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AN INVESTIGATION OF THREE PROBE-AND-DROGUE AERIAL REFUELING TASKS TO EVALUATE LONGITUDINAL CLOSED-LOOP HANDLING QUALITIES (HAVE GAS II)

AFFTC

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This report presents the results of a limited investigation of three probe-and-drogue aerial refueling tasks to evaluate longitudinal closed-loop handling qualities (HAVE GAS II) flight test program. The objective was to identify the best of three tasks for evaluating closed-loop probe-and-drogue aerial refueling (AR) handling qualities. Testing was conducted at Edwards AFB, California, from 17 to 22 April 1997. Three tasks, an AR hookup, a drogue tracking, and a drogue aiming task were evaluated and compared in this test program. These tasks were performed with two different aircraft, the F/A-18B and the NT-33-A. Tanker support was provided by S-3B aircraft from North Island NAS, California. The results of this test will be used to develop an closed-loop, probe-and-drogue demonstration maneuver for MIL-STD-1797A, Flying Qualities of Piloted Aircraft.

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PREFACE

This report presents the results of a limited investigation of three probe-and-drogue aerial refueling tasks to evaluate longitudinal closed-loop handling qualities (HAVE GAS II) flight test program. The purpose of HAVE GAS II was to identify the best of three tasks for evaluating aircraft closed-loop probe-and-drogue aerial refueling handling qualities. The results of this test will be used to develop a closed-loop, probe-and-drogue demonstration maneuver for Military Standard, Flying Qualities of Piloted Vehicles, MIL-STD-1797A (Reference 1).

Testing was conducted at Edwards AFB, California, under the authority of the Commandant, USAF Test Pilot School and Job Order Number M96J0200. Testing was requested by Systems Technology, Inc., and sponsored by Wright Laboratories Flight Dynamics Branch. Sincere appreciation is expressed to VS-29 and VS-41 Squadrons at North Island NAS, San Diego, California, for their outstanding and professional tanker support.

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EXECUTIVE SUMMARY

This report presents the results of a limited investigation of three probe-and-drogue aerial refueling tasks to evaluate longitudinal closed-loop handling qualities (HAVE GAS II) flight test program. The purpose of the HAVE GAS II program was to identify the best of three tasks for evaluating aircraft closed-loop probe-and-drogue aerial refueling (AR) handling qualities. Testing consisted of 7 test sorties, 11.2 flight hours, and was conducted at Edwards AFB, California, from 17 to 22 April 1997. Testing was requested by Systems Technology, Inc., sponsored by Wright Laboratories Flight Dynamics Branch, and was conducted under the authority of the USAF Test Pilot School (TPS). Testing was conducted under USAF TPS Job Order Number M96J0200.

Three tasks were evaluated and compared in this test program. The first task, the AR hookup task, required the pilot to make six attempts to hookup with the drogue. Performance was based on the percentage of successful hookups and whether the hookups could be accomplished without touching the basket webbing. The second task, the drogue tracking task, required the pilot to track the center of the basket with the tip of the refueling probe. Performance was based on how precisely the pilot could track the probe on the center of the basket. The third task, the drogue aiming task, required the pilot to precisely point the tip of the refueling probe onto the center, top, and bottom of the basket. Performance was based on how precisely the probe could be repositioned and stabilized onto the desired aim point.

These tasks were performed with two different aircraft, a National Aeronautics and Space Administration (NASA) F/A-18B and the Calspan Corporation variable stability NT-33A. Tanker support was provided by S-3Bs from North Island NAS, San Diego, California. The intent of this program was not to evaluate the aircraft specifically, but rather to evaluate the effectiveness of the tasks in exposing any AR handling qualities deficiencies. The tasks were evaluated based on their ability to differentiate between aircraft of varying handling qualities levels, to provide consistent handling qualities ratings, and on the pilots' overall qualitative assessment of the tasks.

Overall the drogue tracking task was found to be the best task for evaluating closed-loop probe-and-drogue handling qualities. The drogue tracking task was determined to be satisfactory, the AR hookup task to be marginal, and the drogue aiming task to be unsatisfactory for evaluating closed-loop handling qualities. Turbulence was found to have a significant effect on task performance for all three tasks.

Although the drogue tracking task was found to be better than the AR hookup task for evaluating closed-loop handling qualities, it was limited by not revealing any problems encountered within 5 feet of the drogue (such as receiver bow wave effects pushing the basket). Therefore, it was recommended that a combination of the drogue tracking task and the AR hookup task be flown to thoroughly evaluate an aircraft's closed-loop probe-and-drogue AR handling qualities.

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INTRODUCTION

GENERAL

This report presents the results for a limited investigation of three probe-and-drogue aerial refueling tasks to evaluate longitudinal closed-loop handling qualities (HAVE GAS II) flight test program. The purpose of the HAVE GAS II program was to identify the best of three tasks for evaluating aircraft closed-loop probe-and-drogue aerial refueling (AR) handling qualities.

Testing was conducted at Edwards AFB, California, from 17 to 22 April 1997. Four test sorties in the F/A-18B and 3 test sorties in the NT-33A aircraft, totaling 11.2 hours of flight test, were flown. Four S-3B sorties were flown for tanker support. Four T-38 sorties were flown for photo chase.

Testing was requested by Systems Technology Inc., sponsored by Wright Laboratories Flight Dynamics Branch, and was conducted under the authority of the USAF Test Pilot School. Testing was conducted under USAF Test Pilot School (TPS) Job Order Number M96J0200.

BACKGROUND

Refining the military standard for flying qualities of aircraft, MIL-STD-1797A (Reference 1), into a more mission-oriented document has been an ongoing effort. The final format (e.g., handbook, guidance specification, etc.) for future releases of the flying qualities standard has been in development by the Air Force. A goal of Systems Technology, Inc., under contract from the USAF Flight Dynamics Directorate at Wright Laboratories, was to develop a comprehensive set of mission-oriented, closed-loop handling qualities demonstration maneuvers for fixed-wing aircraft that would complement the quantitative criteria in MIL-STD-1797A (Reference 1). Systems Technology, Inc. provided three different tasks intended to evaluate aircraft closed-loop probe-and-drogue AR handling qualities. The HAVE GAS II flight test program evaluated these tasks for incorporation into the new document.

In the fall of 1993, the USAF Test Pilot School Class 93A conducted a study, *A Limited Handling Qualities Investigation of Rate Command/Attitude Hold and Attitude Command/Attitude Hold Response-Types in the Probe-and-Drogue Air Refueling Task* (HAVE GAS) (Reference 2), of the suitability of different response-type flight control systems for the probe-and-drogue task. The evaluation maneuver required the pilot to attempt probe-and-drogue hookups. Performance criteria were defined in terms of number of attempts to achieve three hookups. During the testing, the evaluation pilots found the performance criteria were too easy and were ineffective at discriminating handling qualities. Even though handling qualities ratings from one through nine were assigned, desired and adequate performance criteria were always achieved. The results of HAVE GAS did not invalidate the probe-and-drogue task as a handling qualities maneuver, but the performance requirements did not aid in the pilots' evaluations. The recommendation was to select an alternative task. The task, similar to the drogue tracking and aiming tasks in this report (Appendix A), was to precisely point the probe at the top, center, and bottom of the basket. Since this task had no defined performance requirement, it was not formally used in the evaluations; however, pilot comments indicated that it was more effective at consistently exposing differences between the configurations.

The closed-loop probe-and-drogue demonstration maneuver in MIL-STD-1797A (Reference 1) at the time of the HAVE GAS II project was the AR hookup task used in this report. The task is similar to the one used in HAVE GAS, except that it contains additional criteria to hookup without hitting the basket webbing. This task had not been evaluated prior to the HAVE GAS II project.

SCOPE

The scope of this investigation was limited by several factors. Only three tasks were considered in identifying the best probe-and-drogue aerial refueling task for evaluating closed-loop handling qualities. No optimization to find the best possible task beyond these three tasks occurred. Furthermore, the evaluation was limited to the longitudinal axis, no lateral-directional evaluation was conducted. Fuel problems and maintenance delays resulted in a limited number of test sorties, however, sufficient data were collected to draw definite conclusions. With both test aircraft, the probe placement was in front of the pilot making it possible to visually line

up the probe with the drogue for the tracking and aiming tasks (Appendix F). The only tanker used for this test was an S-3B. All test sorties were flown in zero to light turbulence.

TEST ITEM DESCRIPTION

Probe-and-Drogue Aerial Refueling Tasks:

Three tasks were evaluated and compared in this test program. All tasks are described in detail in Appendix A. The first task, the AR hookup task, came from the current MIL-STD-1797A (Reference 1). The task required the pilot to attempt at least six hookups with the drogue. Performance criteria were based on the percentage of successful hookups, and whether the basket webbing was touched on successful hookups. The second task, the drogue tracking task, required the pilot to precisely track the center or bottom of the basket with the tip of the probe. Performance criteria were based on how precisely the probe could be tracked at the desired location on the basket. The third task, the drogue aiming task, required the pilot to point the tip of the probe at the center, top, then bottom of the basket. Performance was based on how precisely the probe tip could be repositioned and stabilized at the desired aimpoint on the basket.

Test and Support Aircraft Description:

NT-33A Variable Stability Airplane.

The USAF NT-33A Variable Stability Airplane, tail number 14120, was an extensively modified T-33 jet trainer, operated by Calspan Corporation. A complete description of the variable control system is in Appendix G. Three flight control system (FCS) configurations, designated 2D, 2H, and 2P, were used to evaluate the AR tasks. A brief description of these flight control system configurations along with predicted handling qualities ratings is in Appendix B. The NT-33A was modified with an MD-1 (F-14 version) aerial refueling probe installed on the right side of the nose (Figure F1). The probe extended 2 feet forward and 1 foot above the aircraft nose. The probe was not connected to the NT-33A fuel system. Attached to the head-up display (HUD) was an electronic video sensor similar to those installed on F-15 and F-16 aircraft. The forward visual scene, HUD symbology, as well as the audio channels selected by the front cockpit pilot were recorded on a very high speed (VHS) format video cassette.

McDonnell-Douglas F/A-18B Aircraft.

The F/A-18B aircraft, tail number 161217, was a production representative, dual-seat fighter/attack aircraft owned and operated by NASA. The aircraft had the 8.33 programmable read-only memory (PROM) set flight control system (FCS). There was an AR probe located forward of the pilot's seat on the right side of the fuselage. The probe was extended approximately 2 feet out from the right side of the fuselage for probe-and-drogue refueling (Figure F2). No HUD recording capability was available.

S-3B (Tanker Support).

The tanker support was provided by S-3B aircraft from North Island NAS, San Diego, California. The tanker carried one SF31-301 aerial refueling store (Figures F3 and H1) and illustration in Appendix H under the wing. The SF-31-301 aerial refueling store contained a hydraulically driven hose reel assembly with 50 feet of refueling hose and an attached drogue measuring 2 feet in diameter. White rings marked the hose every 2 feet for the last 20 feet that were unreeled. At the aft end of the store there were three lights: an amber, green and red light. The amber light illuminated when the hose was extended, indicating the test aircraft could engage the drogue. After engagement, the test aircraft moved forward to extinguish the amber light. During normal refueling, the green light indicated that fuel was flowing. The red light was a signal for emergency breakaway. More information on refueling stores and procedures can be found in the *Naval Air Training and Operating Procedures Standardization* (NATOPS) *Air-to-Air refueling manual* (Reference 3).

TEST OBJECTIVE

The overall objective of HAVE GAS II was to identify the best of three tasks for evaluating aircraft closed-loop probe-and-drogue AR handling qualities. All tasks are described in Appendix A. The specific objectives were as follows:

1. Assess the adequacy of the AR hookup task for the purpose of evaluating closed-loop probe-and-drogue AR handling qualities.

2. Assess the adequacy of the drogue tracking task, and its variations, for the purpose of evaluating closed-loop probe-and-drogue AR handling qualities.

3. Assess the adequacy of the drogue aiming task, and its variations, for the purpose of evaluating closed-loop probe-and-drogue AR handling qualities, and compare the results to those obtained in the evaluation of the AR hookup and drogue tracking tasks.

All objectives were met. Although the success criteria outlined in the test plan were met, only minimal data were collected.

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TEST AND EVALUATION

TEST PROCEDURES

General:

The purpose of this effort was to evaluate three probe-and-drogue AR tasks to identify the best task for evaluation of closed-loop AR handling qualities. These tasks were performed with two different aircraft, the F/A-18B and the NT-33A. An S-3B aircraft from North Island NAS, San Diego, California, carrying an AR store under the left wing (Figure H1) provided tanker support. The testing consisted of seven sorties: four in the F/A-18B and three in the NT-33A aircraft. The intent of this program was not to evaluate the aircraft specifically, but rather to evaluate the effectiveness of the tasks in exposing any AR handling qualities deficiencies. The tasks are described in Appendix A.

The scope of the investigation was limited to three tasks. No optimization to find the best possible task beyond the three tasks occurred. The evaluation was limited to the longitudinal axis only. Fuel problems and maintenance delays resulted in a very limited number of test sorties. With both test aircraft, the probe placement was in front of the pilot making it possible to visually line up the probe with the drogue for the tracking and aiming tasks (Appendix F). The only tanker used for this test was a S-3B aircraft. All test sorties were flown in zero to light turbulence.

Three evaluation pilots were used in the test program. Two pilots (pilots A and B) had no previous probe-and-drogue refueling experience but did have boom AR experience. Both pilots flew one training sortie in the NT-33A, one data sortie in the NT-33A, and at least one data flight in the F/A-18B aircraft. The third evaluation pilot (pilot C), who had previous probe-and-drogue refueling experience in the F/A-18 aircraft, flew one data sortie in both the F/A-18B and NT-33A aircraft. Data from pilot C's NT-33A sortie consisted only of qualitative comments on the AR tasks. This was due to a different stick gain setting than in the other two NT-33A data flights (Appendix I). Table 1 shows the data sorties flown.

Three different FCS configurations were flown in the NT-33A aircraft (2P, 2D, and 2H, described in Appendix B). The FCS configurations were verified in flight by Calspan Corporation prior to arriving at Edwards AFB (Appendix B). They were verified again by step inputs performed on the first NT-33A data flight. Since the stick gain was reduced for the last two data flights, both a windup turn and step inputs were performed to verify stick gain setting and FCS configurations on the last two data sorties.

Evaluation Criteria:

Each task was evaluated in three areas. First, each task was evaluated on its ability to differentiate between aircraft, or FCS configurations, of varying handling qualities levels. Each pilot's Cooper-Harper (CH) and pilot-induced oscillation (PIO) ratings

Table 1
TEST SORTIE MATRIX FOR HAVE GAS II

Data Sortie	Test Aircraft	Date Flown	Pilot	Chased
1[1]	NT-33A	17 April	C	Yes
2	F/A-18B	18 April	A	Yes
3	F/A-18B	18 April	B	No
4	NT-33A	21 April	B	Yes
5	F/A-18B	21 April	C	Yes
6	NT-33A	21 April	A	Yes
7	F/A-18B	22 April	A	Yes

Note: 10,000 to 12,000 feet mean sea level, 250 to 275 KIAS, 17 to 22 April 1997.

[1]Different stick gain setting than on other NT-33A sorties, Cooper-Harper and pilot-induced oscillation ratings not used.

ratings and comments on aircraft handling qualities were evaluated individually to see if a given task allowed the pilot to differentiate between aircraft and FCS configurations. The CH and PIO rating scales are illustrated in Figures E1 and E2. To do this, it was assumed that the aircraft and FCS configurations had known handling qualities based on previous flight tests or predictions (Appendix B). Both the F/A-18B and NT-33A 2D configuration were predicted to have level 1 handling qualities. The NT-33A 2H configuration was predicted to have level 2 handling qualities, and configuration 2P was predicted to be level 2 and fall in between 2H and 2D.

Second, each task was evaluated on its ability to provide consistent CH and PIO ratings and pilot comments. Ratings were considered consistent if they varied by two or less. Each task was examined to see if different pilots gave similar CH and PIO ratings and comments on aircraft handling qualities.

Finally, each task was evaluated based on pilot qualitative comments on the task. Each task was rated on operational representation, pilot gains, ease of determining performance criteria, pilot confidence in assigning a CH rating, ability to evaluate closed-loop handling qualities, and overall worth of the task.

Due to the limited number of sorties and the effect of turbulence on some CH ratings (see Daily Flight Report for data sortie No. 6 in Appendix D), the pilot comments on the tasks were the overriding factor in determining the adequacy of a task.

Performing the AR Tasks:

The evaluation of each task in flight was a two-step process. First, the pilot flew the task and evaluated the aircraft configuration by assigning CH and PIO ratings, and making comments on the aircraft's handling qualities. Secondly, the pilot evaluated how well the task aided them in evaluating aircraft closed-loop handling qualities and in exposing handling qualities deficiencies. The data collected was pilot questionnaires and comments (Appendix C).

The tasks were always performed in the following order:

1. The AR hookup task,
2. The drogue tracking task, and
3. The drogue aiming task.

For the NT-33A flights, each FCS configuration was flown through all tasks before the next FCS configuration was programmed. The order of the flight control configurations was unknown to the test pilot until after all NT-33A test missions were flown.

After completing one task, the test aircraft moved to a position at least 100 feet to the left of the precontact position. The project test pilot completed the questionnaire and assigned applicable CH and PIO and turbulence ratings for that task. For the NT- 33A flights, the safety pilot programmed the next flight control configuration. The project test pilot conducted low bandwidth tracking of the tanker as a warmup exercise until he/she was comfortable with the current flight control system. When the tanker and test aircraft were ready, the project test pilot moved to the precontact position. The test aircraft repeated the process for the next task and/or flight control configuration.

A chase aircraft was used on all but sortie No. 3 to provide the test aircraft with distance from the probe to the drogue as seen from an abeam position. This helped to standardize tracking distances between evaluation pilots. A standardized tracking distance was important, because the distance from the basket effected pilot gains and assessment of workload and compensation. The chase used predetermined references on the test aircraft to determine distance. The chase aircraft remained on the test aircraft's left wing throughout the drogue extension procedure. After the test aircraft moved into precontact position, the chase aircraft moved to a position abeam the test aircraft (right or left side), with 100 to 200 feet spacing from both the tanker and the test aircraft. In addition to providing distance calls to the test aircraft the chase also took video of the tasks. On data sortie No. 3 an experienced

probe-and-drogue instructor pilot (in the back seat of the test aircraft) was used to help verify tracking distances. There was not a significant difference in the results obtained from data sortie No. 3. However, the pilot could not positively ensure that the same tracking distance was used as in all the other data sorties.

AR Hookup Task.

The AR hookup task, consisted of six attempts at a hookup. The test aircraft began the task evaluation from the precontact position (10 to 15 feet aft of the drogue). The test aircraft closed with 3 to 5 knots of closure, performed a hookup attempt, and returned to precontact position six times in a row. If momentary basket excursions due to turbulence caused the pilot to abandon an attempted hookup or hit the basket webbing during an approach, the attempt was not counted as one of the six attempts for performance assessment.

Drogue Tracking Task.

The drogue tracking task was flown three times in a row before any ratings were assigned. The task was performed with 6 to 8 feet of separation from the tip of the refueling probe to the edge of the basket. If the adequate performance criteria (with no PIO tendencies) were met, the task was performed with 3 to 4 feet of separation. On data sortie No. 7 tracking at 10 to 20 feet was also performed. On all sorties, except sortie No. 3, the distance was verified by a chase aircraft. Distance on sortie No. 3 was verified by an experienced instructor pilot from the rear cockpit of the test aircraft. Time was varied on the tracking task only if the pilot needed more time to assess a CH and PIO rating. Momentary basket excursions due to turbulence were not included when assessing performance.

Drogue Aiming Task.

The drogue aiming task was flown three times in a row before any ratings were assigned. The task was performed with 6 to 8 feet of separation from the tip of the refueling probe to the edge of the basket. If adequate performance criteria (with no PIO tendencies) were obtained, the task was performed with 3 to 4 feet of separation. On all sorties, except sortie No. 3, the distance was verified by a chase aircraft. Distance of sortie No. 3 was verified by an experienced instructor pilot from the rear cockpit of the test aircraft. Momentary basket excursions due to turbulence were not included when assessing performance.

Data Collection:

The primary data collected were CH and PIO ratings and pilot comments. The primary means of data collection in the NT-33A aircraft was the HUD video which recorded the tasks, pilot comments, and flight conditions. An Ampex AR700 flight data recorder recorded NT-33A aircraft parameters, such as stick forces, angle of attack, pitch rate, control surface deflections, etc. On the F/A-18 aircraft, a cassette recorder was the primary means of collecting comments and ratings, with handwritten comments as a backup. Five sorties were also recorded on video from a chase aircraft. After the flight, the pilot reviewed the video or audio recording of the flight (if available) and debriefed with a project engineer to clarify ratings and comments. A daily flight test report was completed after each flight. A summary of CH and PIO ratings and task questionnaires is presented in Appendix C. All daily flight test reports are in Appendix D.

TEST RESULTS

Overall:

All objectives were met. Overall the drogue tracking task was found to be the best task for evaluating closed-loop probe-and-drogue handling qualities. The drogue tracking task was determined to be satisfactory, the AR hookup task to be marginal, and the drogue aiming task to be unsatisfactory for evaluating closed-loop handling qualities. The terms satisfactory, marginal and/or unsatisfactory were used for evaluation (Figure E3).

Although the drogue tracking task was found to be the best task for evaluating closed-loop handling qualities, it was limited by not revealing any problems occurring within 5 feet of the drogue (such as receiver bow wave effects pushing the basket). The drogue tracking task could be improved to be a better task if combined with the AR hookup task.

A combination of the drogue tracking task followed by the AR hookup task should be flown when evaluating an aircraft's closed-loop probe-and-drogue handling qualities. (R)[1]

Throughout the test program turbulence had a significant effect on all tasks performed. Even in light turbulence the basket motion made it extremely difficult for the pilots to accurately assess aircraft performance. The turbulence scale used during the test (Figure E4) was inadequate for rating turbulence effects on the tasks. It only accounted for aircraft motion, and even light turbulence resulted in basket motion large enough to make the tracking and aiming tasks sometimes impossible to perform. A turbulence effect rating scale that qualifies the deterioration of task performance due to turbulence may have been more useful than the scale used in this test program. One potential scale is the Turbulence Effect Rating Scale (Figure E5); however, this scale was not used during the test.

In performing the drogue tracking and aiming tasks, distance calls from a chase aircraft were used to confirm that all pilots were using the same distance from the probe to the basket. The common tendency was for pilots to think they were closer to the basket than they were. Since pilot gains were affected by the proximity between the probe and drogue, it was important to standardize the distance.

A summary of all CH and PIO ratings and pilot questionnaires is contained in Appendix C. Daily Flight Reports with full pilot comments are in Appendix D.

Adequacy of the AR Hookup Task:

The AR hookup task was somewhat satisfactory for evaluating closed-loop probe-and-drogue AR handling qualities. The greatest strength of this task was that it was the most operationally representative while the primary weakness was that desired performance could be attained with a bad aircraft by flying the task very low gain and partially open-loop.

Ability of the Task to Differentiate Between Aircraft of Varying Handling Qualities Levels.

The AR hookup task was satisfactory for differentiating between aircraft with different levels of handling qualities ratings. When flown by three different evaluation pilots, the CH and PIO ratings for the AR hookup task showed the F/A-18B aircraft to be a level 1 airplane for AR. This agreed with the predicted results. Overall, the AR hookup task did show that the 2D FCS was better than the 2H FCS, as predicted. There was not a significant distinction in ratings between the 2D and 2P systems. When the PIO ratings were used along with the CH ratings, the distinction was more evident. And finally, if turbulence effects were taken into account, the data did show an ability to differentiate between the various NT-33A flight control systems with different levels of handling qualities ratings.

Ability to Provide Consistent CH and PIO Ratings and Pilot Comments.

The AR hookup task was marginally satisfactory for providing consistent CH and PIO ratings and was moderately adequate for providing consistent pilot comments. The inconsistent CH and PIO ratings were primarily attributed to turbulence effects on data sortie No. 6. The pilot comments for this task were consistent, however. Each pilot said the task was well defined, understandable, and the performance criteria were easily applied.

Pilot Qualitative Assessment of the Task.

All pilots commented that the AR hookup task was the most operationally representative task. Accounting for drogue "webbing hits" during aerial refueling helped differentiate between aircraft handling qualities levels by forcing the pilot to fly more closed-loop. Also, any attempt at a last second,

[1] An R within parentheses at the end of a paragraph corresponds to the bolded recommendation in the Conclusions and Recommendations section of this report.

correction by the pilot also helped differentiate between good and bad airplanes. Of all the tasks flown, the AR hookup task was the least affected by turbulence; the task description allowed the pilot to account for turbulence effects by discounting the attempt. Probe placement on the test aircraft did affect the task. When the probe was almost directly in front of the pilot, as in the NT-33A aircraft, the pilots found it fairly easy to line the probe up with the drogue basket. With the probe further offset to the side, as in the F/A-18 aircraft, the pilots found it more difficult to line the probe up with the basket. However, there was also a certain learning curve involved. After one or two attempts, the pilot would get the lineup picture and then a series of successful hookups would follow. Wake turbulence from the tanker was noticeable but did not affect the task. Bow wave effects on the task were evident only on the F/A-18 aircraft when a lateral correction was made close to the basket (within 5 feet). Also, the specified 3- to 5-knot closure rate used in the task was acceptable.

The pilots commented that the AR hookup task did not accurately reveal aircraft closed-loop probe-and-drogue AR handling qualities in all cases. Often the CH ratings were driven by pilot compensation versus task performance, thus making the ratings more subjective and less performance driven. In particular, given a level 2 airplane, no turbulence and/or basket motion, and a good set up at 8 to 10 feet, it was demonstrated that it was possible to achieve hookups, without hitting the webbing. This was accomplished by flying the task at very low gain. In addition, the more AR experience a pilot had, the greater the task was influenced by their "learning curve" (i.e., the more likely they were to fly the task open-loop and make an airplane with poor handling qualities perform well). Last second, "end-game" corrections to score a direct hit were discouraged by the nature of the task. Finally, the pilots commented that there was no need to stabilize for a full 30 seconds after hooking up since pilot gains were reduced immediately after initial stabilization.

Adequacy of the Drogue Tracking Task:

The drogue tracking task was found to be moderately satisfactory for evaluating closed-loop probe-and-drogue AR handling qualities. It showed the most consistent ratings and comments, while having very well defined performance criteria. Its greatest weakness was its inability to reveal handling qualities deficiencies at very close range to the basket.

Ability to Differentiate Between Aircraft of Varying Handling Qualities Levels.

The drogue tracking task was satisfactory in its ability to differentiate between aircraft of varying handling qualities levels. Quantitatively, the CH and PIO ratings showed a definite trend from good aircraft to bad aircraft. The quantitative ratings and qualitative comments from the pilots showed the expected handling qualities trend. The level 1 flight control systems had no undesirable motions, good predictability, and comfortable response, while the level 2 flight control systems had increasingly more undesirable motions, poorer predictability, and slower response.

Ability to Provide Consistent CH and PIO Ratings and Pilot Comments.

The drogue tracking task was satisfactory for producing very consistent CH ratings, PIO ratings, and pilot comments. The variation of CH ratings was no more than 2, with the same variation for PIO ratings. The performance criteria achieved was found to be similar among the pilots, and pilot compensation was also described similarly for a given aircraft and/or FCS.

Pilots Qualitative Assessments of Task.

The pilots assessed the drogue tracking task as moderately good to very good overall. However, it was only considered marginal as an operationally representative task. On one hand the task represented a maneuver similar to lining up from the precontact position, while on the other hand, it lacked the true nature of aerial refueling where last minute corrections near the basket may have been necessary.

Turbulence was found to have significant effects on the behavior of the drogue basket, which lowered the pilot's confidence in their CH rating at all tracking distances. The effect of turbulence was more pronounced at shorter tracking distances.

The drogue tracking task was considered well defined, which made it easy for the pilot to determine their performance. Throughout the test sorties, the

pilots agreed that the closer tracking distance (3 to 4 feet) was not a desirable task; it was less operationally representative, had a higher potential for aircraft damage (e.g., F/A-18B aircraft where the probe tip is 6 feet aft of the nose), and generally produced higher pilot gains than are operationally representative. The best distance found for this drogue tracking task was 6 to 10 feet. A minimum of 20 seconds was required before an effective evaluation could be made. In some cases more than 20 seconds was required due to basket motion corrupting task performance. To accommodate these momentary excursions, the drogue tracking task was refined such that the duration of tracking should be at least 20 seconds, and as long as the pilot needs to assign ratings with high confidence.

Adequacy of the Drogue Aiming Task:

The drogue aiming task was found to be moderately inadequate for evaluating closed-loop probe-and-drogue AR handling qualities due to a lack of ability to judge performance criteria and the dependency of achieved performance on pilot aggressiveness. It was difficult to establish reasonable performance criteria for this task that could be consistently performed and accurately measured.

Ability of the Task to Differentiate Between Aircraft of Varying Handling Qualities Levels.

The ability of the drogue aiming task to differentiate between aircraft of varying handling qualities levels was satisfactory. The CH and PIO ratings clearly indicated the relative handling qualities between the various aircraft flown.

Ability to Provide Consistent CH And PIO Ratings and Pilot Comments.

The ability of the drogue aiming task to provide consistent CH and PIO ratings and pilot comments was moderately unsatisfactory. Two project pilots gave the NT-33A FCS configurations 2P and 2H drastically different ratings. For this task, one pilot rated configuration 2P level 1 while the other pilot rated 2P level 3. Inconsistent ratings were evidence of a task that is difficult to execute.

Pilots Qualitative Assessments of the Task.

The drogue aiming task had three common deficiencies that each pilot noted. First, this task was highly dependent on pilot aggressiveness. A more aggressive attempt resulted in worse CH and PIO ratings. It was difficult for all pilots to consistently perform the proper level of aggressiveness for this task. Secondly, it was sometimes difficult to determine if the performance criteria were met. Finally, all pilots commented that this task was the least operationally representative of the three tasks evaluated. The control inputs required to conduct this task are not used when conducting actual probe-and-drogue refueling, even during periods of correcting for errors in setup or movements of the basket. These deficiencies, along with the inability to provide consistent ratings, made the drogue aiming task moderately inadequate for evaluating aircraft closed-loop probe-and-drogue handling qualities.

CONCLUSIONS AND RECOMMENDATIONS

Overall the drogue tracking task was found to be the best task for evaluating closed-loop probe-and-drogue aerial refueling (AR) handling qualities. The drogue tracking task was determined to be satisfactory in evaluating closed-loop AR handling qualities, because it showed the most consistent ratings and comments on aircraft handling qualities, while having very well defined performance criteria. The only weakness was its inability to reveal handling qualities problems, such as the receiver bow wave pushing the basket away, at close range to the basket. The AR hookup task was found to be marginal. The greatest strength of this task was that it was the most operationally representative, while the primary weakness was that desired performance could be attained with a bad aircraft by flying the task very low gain and partially open-loop. The drogue aiming task was found to be unsatisfactory due to a lack of ability to judge performance criteria and the dependency of achieved performance on pilot aggressiveness.

Although the drogue tracking task was found to be better than the AR hookup task for evaluating closed-loop handling qualities, it was limited by not revealing any problems that were encountered within 5 feet of the basket. The drogue tracking task could be improved to be a better task if combined with the AR hookup task.

> ***A combination of the drogue tracking task followed by the AR hookup task should be flown when evaluating an aircraft's closed-loop probe-and-drogue handling qualities. (Page 8)***

Throughout the test program turbulence had a significant effect on all tasks performed. Even in light turbulence the basket motion made it extremely difficult for the pilots to accurately assess aircraft performance. A turbulence effect rating scale that qualifies the deterioration of task performance due to turbulence would have been more useful than the scale used in this test program.

In performing the drogue tracking and aiming tasks, distance calls from a chase aircraft were used to confirm that all pilots were using the same distance from the probe to the basket. The common tendency was for pilots to think they were closer to the basket than they were. Since pilot gains were affected by the proximity between the probe and drogue, it was important to standardize the distance.

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APPENDIX A

TASK DESCRIPTION AND PERFORMANCE CRITERIA

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TASK DESCRIPTION AND PERFORMANCE CRITERIA

AR HOOKUP TASK (CURRENTLY IN MIL-STD-1797A)

Task Description:

From the precontact position, (10 to 15 feet behind the drogue with the refueling probe in line both vertically and horizontally) establish a 3- to 5-knot closure rate and attempt to make contact. If the hookup is successful, stabilize for approximately 30 seconds, then establish a 3- to 5-knot separation rate to disconnect and return to the precontact position. Repeat the task at least six times, then assign a Cooper-Harper (CH) and Pilot-Induced Oscillation (PIO) rating.

A hookup attempt is defined as an approach from 15 feet with an intent to hookup. If the closure rate stops or if the closure rate exceeds 5 knots, abort the attempt. If the probe tip passes the outside edge of the drogue basket or a hazardous situation develops, abort the hookup attempt and return to the precontact position. Aborted attempts caused by momentary basket excursions due to turbulence will not be counted as an attempt.

Performance Criteria:

Desired Performance.

1. Hookup without touching basket webbing in at least 50 percent of the attempts.

2. No PIO observed.

Adequate Performance.

1. Hookup in at least 50 percent of the attempts.

DROGUE TRACKING TASK

Task Description:

Stabilize the probe 6 to 10 feet aft of the basket. From this position, keep the probe within the edges of the basket for at least 20 seconds, using the center of the basket as the aim point. Repeat the task at least three times. Assign a CH and PIO rating and complete a pilot questionnaire (Figure A1).

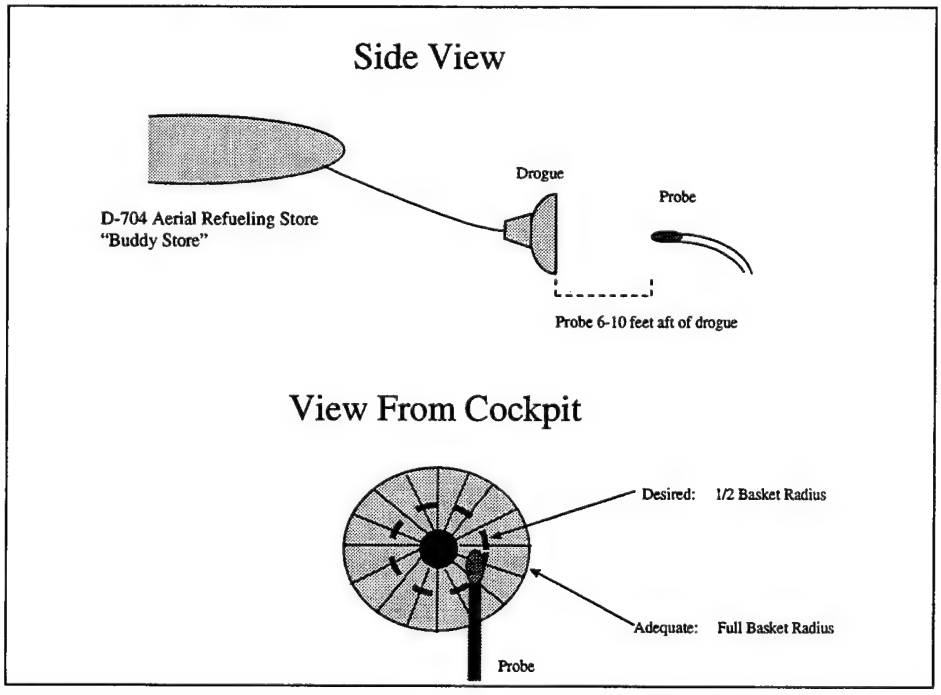

Figure A1 Drogue Tracking Task

Performance Criteria:

Desired Performance.

1. Maintain the probe vertically and laterally within ½-basket radius of the desired position.

2. No contact with the basket (unless sudden basket motion is caused by the tanker or external influences).

3. No PIO observed.

Adequate Performance.

1. Maintain the probe vertically and laterally within one basket radius of the desired position.

2. No contact with the basket (unless sudden basket motion is caused by the tanker or external influences).

NOTE

Momentary excursions outside the desired or adequate limits that are considered to be a result of basket motion and beyond the control of the evaluation pilot should not be considered when assessing overall performance.

DROGUE AIMING TASK

Task Description:

After the probe is stabilized at a 6- to 10-foot distance from the basket, quickly reposition (within 1 second) the drogue at the top edge of the basket and stabilize for 5 seconds. Then, quickly reposition (within 2 seconds) the probe at the bottom edge of the basket and stabilize for 5 seconds. Finally, quickly reposition the probe in the center of the basket (within 1 second). Assign a CH and PIO rating and complete a pilot questionnaire (Figure A2).

Performance Criteria:

Desired Performance.

1. Maintain the probe vertically and laterally within ½-basket radius of the desired position.

2. No contact with the basket (unless sudden basket motion is caused by the tanker or external influences).

3. No PIO observed.

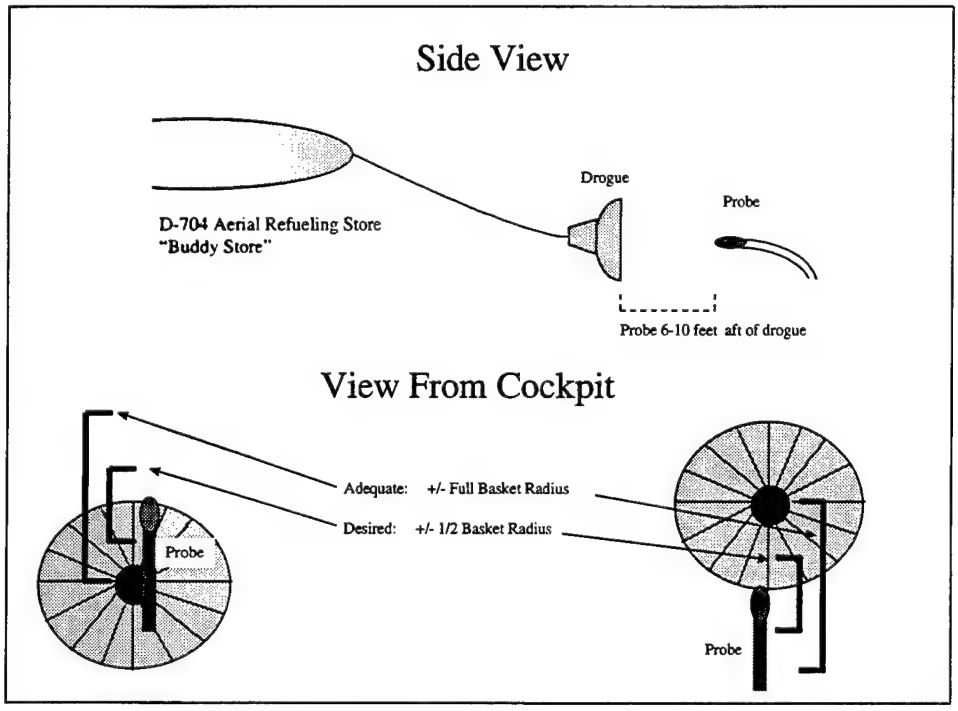

Figure A2 Drogue Aiming Task

Adequate Performance.

1. Maintain the probe vertically and laterally within 1-basket radius of the desired position.

2. No contact with the basket (unless sudden basket motion is caused by the tanker or external influences).

NOTE

Momentary excursions outside the desired or adequate limits that are considered to be a result of basket motion and beyond the control of the evaluation pilot should not be considered when assessing overall performance.

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APPENDIX B

FLIGHT CONTROL SYSTEM CONFIGURATIONS AND PREDICTED RATINGS VALIDATION

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FLIGHT CONTROL SYSTEM CONFIGURATIONS AND PREDICTED RATINGS VALIDATION

GENERAL

The predicted handling qualities of the three flight control system configurations flown on the variable-stability NT-33A and of the F/A-18B aircraft are presented in this appendix (Reference 4).

THE NT-33A AIRCRAFT

Three different flight control system configurations, designated 2D, 2H, and 2P, were flown on the NT-33A aircraft. The longitudinal configuration is shown in Figure B1 and the short-period approximations for θ/δ_e are listed in Table B1. Both 2D and 2H came from an NT-33A study by Neal and Smith to develop control system design criteria for fighter airplanes (Reference 5). Configurations 2D and 2H were evaluated again in an investigation of the Neal-Smith Criteria conducted by USAF Test Pilot School (TPS) (Reference 6). The third configuration is a new case designed for HAVE LIMITS (a pitch rate limiting investigation) that was tested at the USAF TPS (Reference 4).

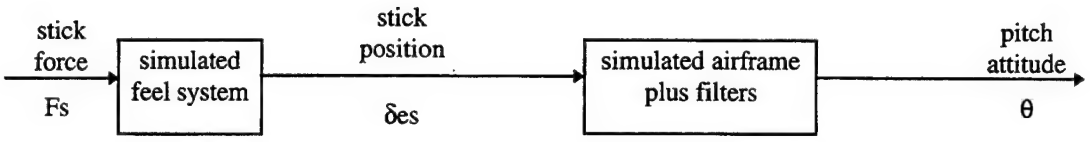


Figure B1 Block Diagram of Longitudinal System

Table B1
AIRFRAME PLUS FILTERS

Configuration	$\theta/\delta_e(s)$
2D	$\frac{7(s+1.25)}{s[s^2+2(0.7)(4.9)s+4.9^2]}$
2H	$\frac{14(s+1.25)}{s(s+2)[s^2+2(0.7)(4.9)s+4.9^2]}$
2P	$\frac{28(s+1.25)}{s(s+4)[s^2+2(0.7)(4.9)s+4.9^2]}$

Each of these configurations has the same basic short-period dynamics (short-period damping [ζ_{sp}] = 0.7, short-period frequency [ω_{sp}] = 4.9 radians/second); however, the configurations have different lag filters (no lag filter for 2D). These configurations made the NT-33A aircraft have different longitudinal handling qualities while the lateral dynamics were unchanged. Table B2 is a summary of the handling qualities ratings given in previous evaluations and the predicted handling qualities levels for HAVE GAS II. The predicted handling quality levels were based on previous flight tests for configurations 2D and 2H, and based on R Smith criteria for configuration 2P.

Configuration 2D served as the baseline level 1 aircraft for HAVE GAS II and configuration 2H served as the baseline level 2 aircraft. Configuration 2P was expected to provide handling qualities between those for configurations 2D and 2H (Reference 4). The stick gain corresponded to 25 pounds/g (625 potentiometer setting) on the first NT-33A flight, and was determined to be too high. The gain was optimized on the subsequent training flights to 37 pounds/g (475 potentiometer setting). This setting was used for the last two data flights in the NT-33A aircraft.

THE F/A-18B AIRCRAFT

The F/A-18A aircraft had reported level 1 handling qualities for operational refueling (Reference 7); the F/A-18B was expected to be as good or better than the F/A-18A aircraft. (The F/A-18B aircraft flown for this investigation had the 8.33 programmable read-only memory [PROM] set flight control system.) According to Reference 7, normal plugging required minimal pilot compensation and resulted in a handling quality rating of 3. However, performing a longitudinal task of capturing the area of the center of the drogue from a four-foot low offset position required moderate pilot compensation handling quality rating 4 (HQR-4), provided the pilot kept aggressiveness low. If the pilot was more aggressive, considerable compensation was required and resulted in a handling quality rating of 5. Finally, the pilot was unable to perform the desired task of capturing the area of the center of the drogue from a lateral offset position, resulting in a handling quality rating of 7.

VALIDATION DATA

The following model validation results are provided in this appendix.

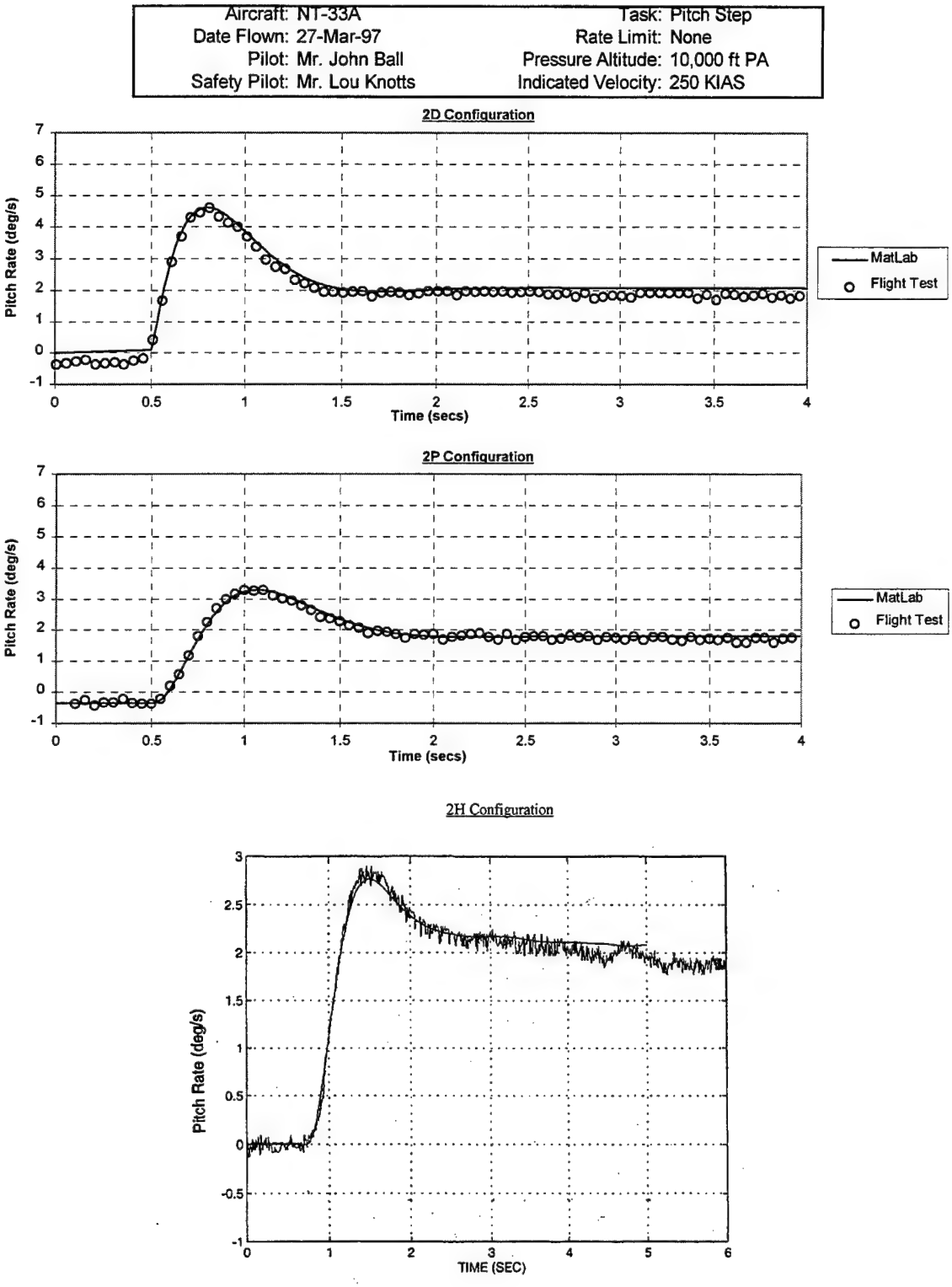
1. Comparison of time-domain pitch response from the NT-33A flight test and MATLAB^{R} 4.2c predictions. Comparisons are provided for the 2D, 2P, and the 2H aircraft models.

2. Flight test frequency response, phase and magnitude, for the aircraft models, 2D, 2P, and 2H. The frequency response was generated with data from 40-second manual longitudinal stick sweeps. The flight test frequency response is compared to a lower order equivalent system (LOES) estimation for 2nd order response. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 1) weighting function.

Table B2
HANDLING QUALITIES RATINGS

	Configuration		
Handling Qualities Ratings	2D	2H	2P
Neal-Smith evaluation	2.5, 2.5, 3	5, 5.5, 6	not flown
TPS TMP evaluation	2, 2, 3, 3, 4	4, 4, 5, 6, 6	not flown
Two-Phase AR evaluation	1, 1, 2	not flown	not flown
Predicted Handling Qualities Level:	Level 1	Level 2	Level 2

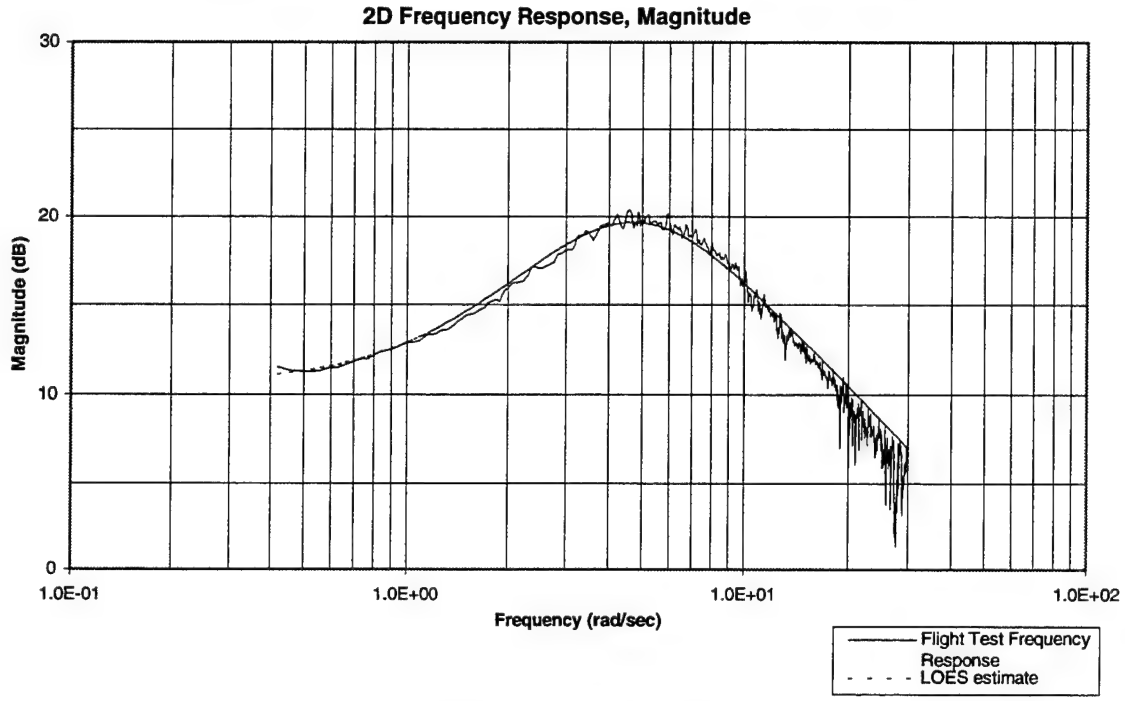
Notes: 1. TPS - Test Pilot School
2. TMP -
3. AR - aerial refueling

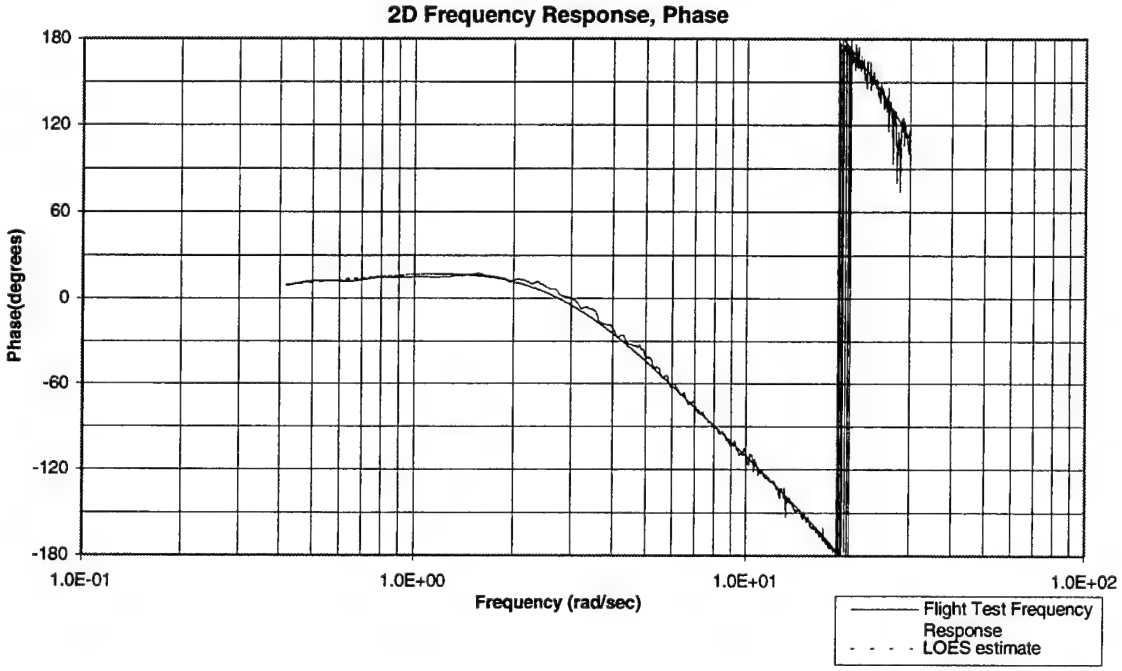


Note: Preflight predictions were generated with MATLAB[R] 4.2c.

Figure B2 Comparison of NT-33A Flight Test Aircraft Model Pitch Step Response to Preflight Predictions For 2D, 2P, And 2H.

Aircraft: NT-33A	Task: Freq. Response
Date Flown: 27-Mar-97	Rate Limit: None
Pilot: Mr. John Ball	Pressure Altitude: 10,000 ft PA
Safety Pilot: Mr. Lou Knotts	Indicated Velocity: 250 KIAS

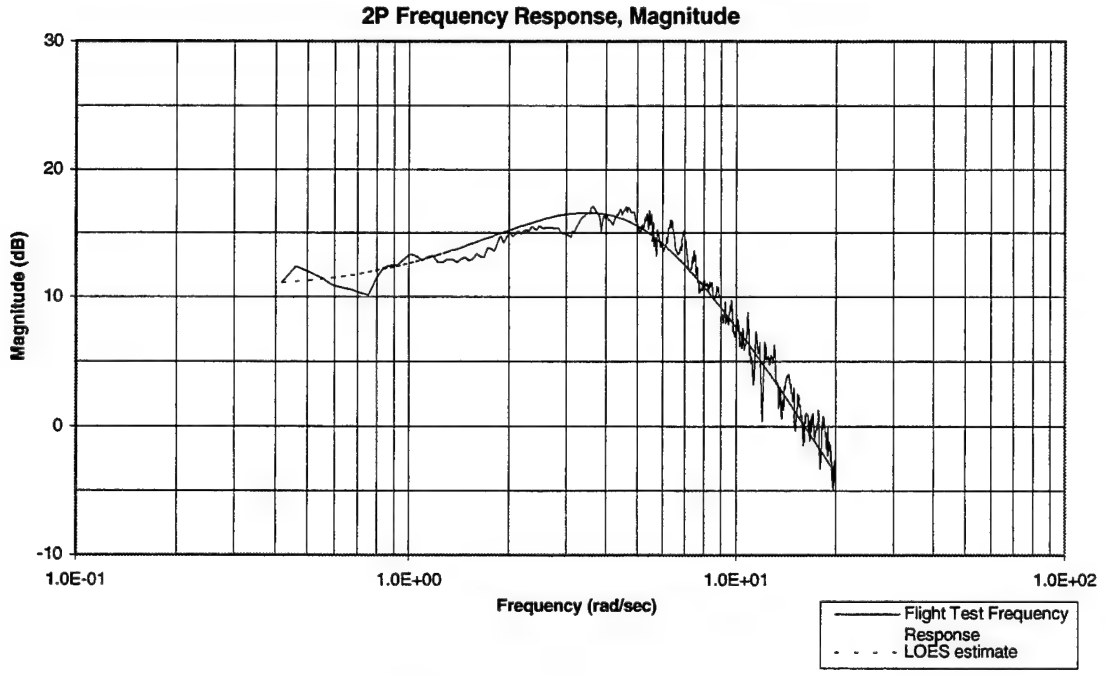


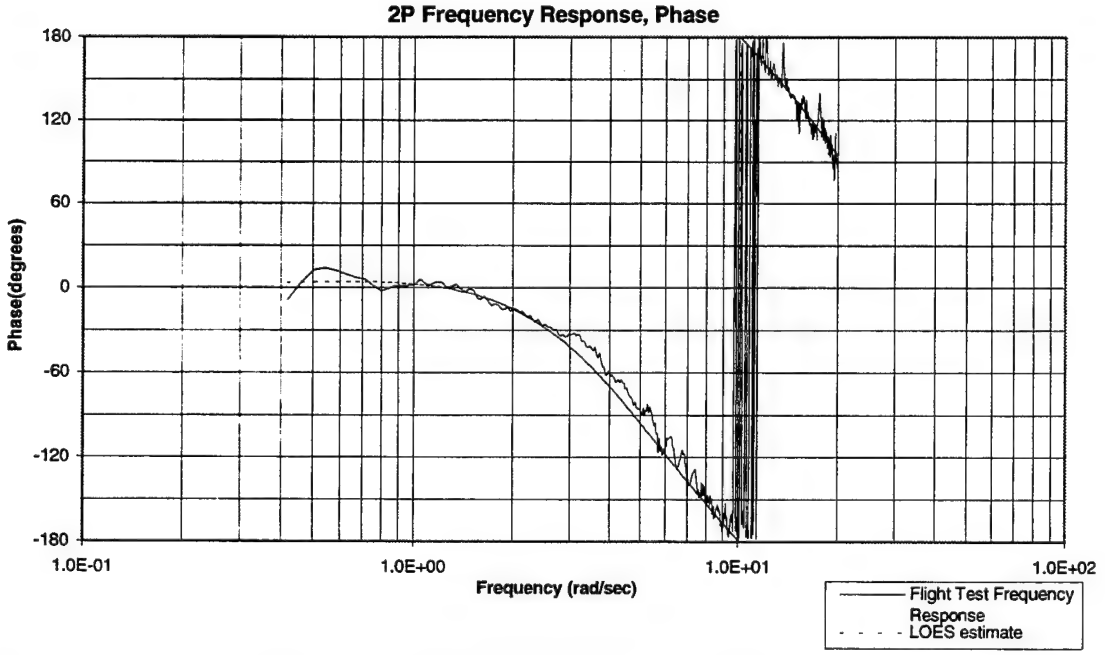


Notes: 1. Flight test frequency response was generated from a 40-second manual frequency sweep.
2. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 1) weighting function.

Figure B3 Comparison of NT-33A Flight Test Pitch Frequency Response to Lower Order Equivalent Systems (LOES) Estimation For the 2D Aircraft Model.

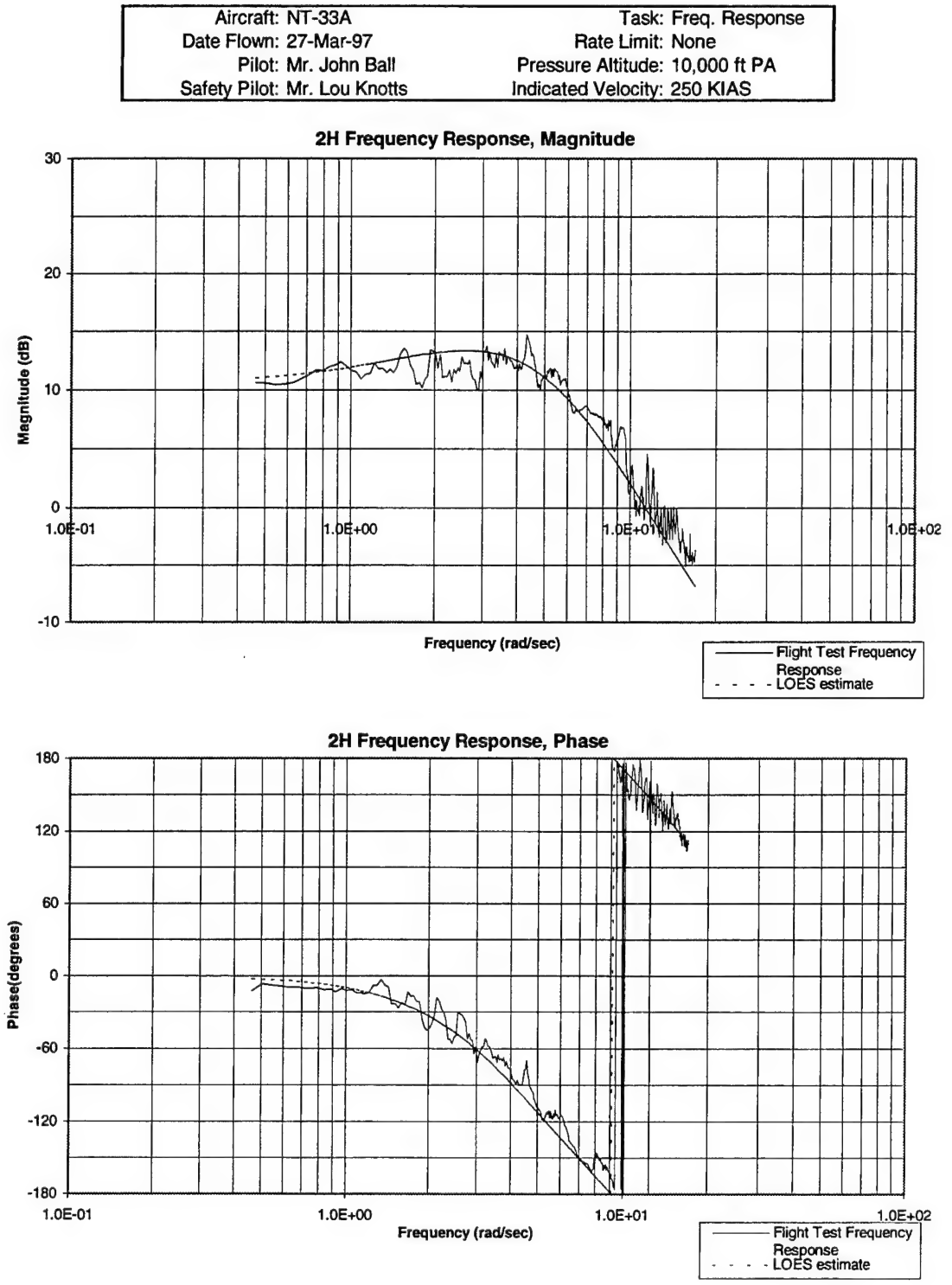
Aircraft: NT-33A	Task: Freq. Response
Date Flown: 27-Mar-97	Rate Limit: None
Pilot: Mr. John Ball	Pressure Altitude: 10,000 ft PA
Safety Pilot: Mr. Lou Knotts	Indicated Velocity: 250 KIAS





Notes: 1. Flight test frequency response was generated from a 40-second manual frequency sweep.
2. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 1) weighting function.

Figure B4 Comparison of NT-33A Flight Test Pitch Frequency Response to Lower Order Equivalent Systems (LOES) Estimation For the 2P Aircraft Model.



Notes: 1. Flight test frequency response was generated from a 40-second manual frequency sweep.
2. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 1) weighting function.

Figure B5 Comparison of NT-33A Flight Test Pitch Frequency Response to Lower Order Equivalent Systems (LOES) Estimation For the 2H Aircraft Model.

APPENDIX C

FLIGHT TEST DATA

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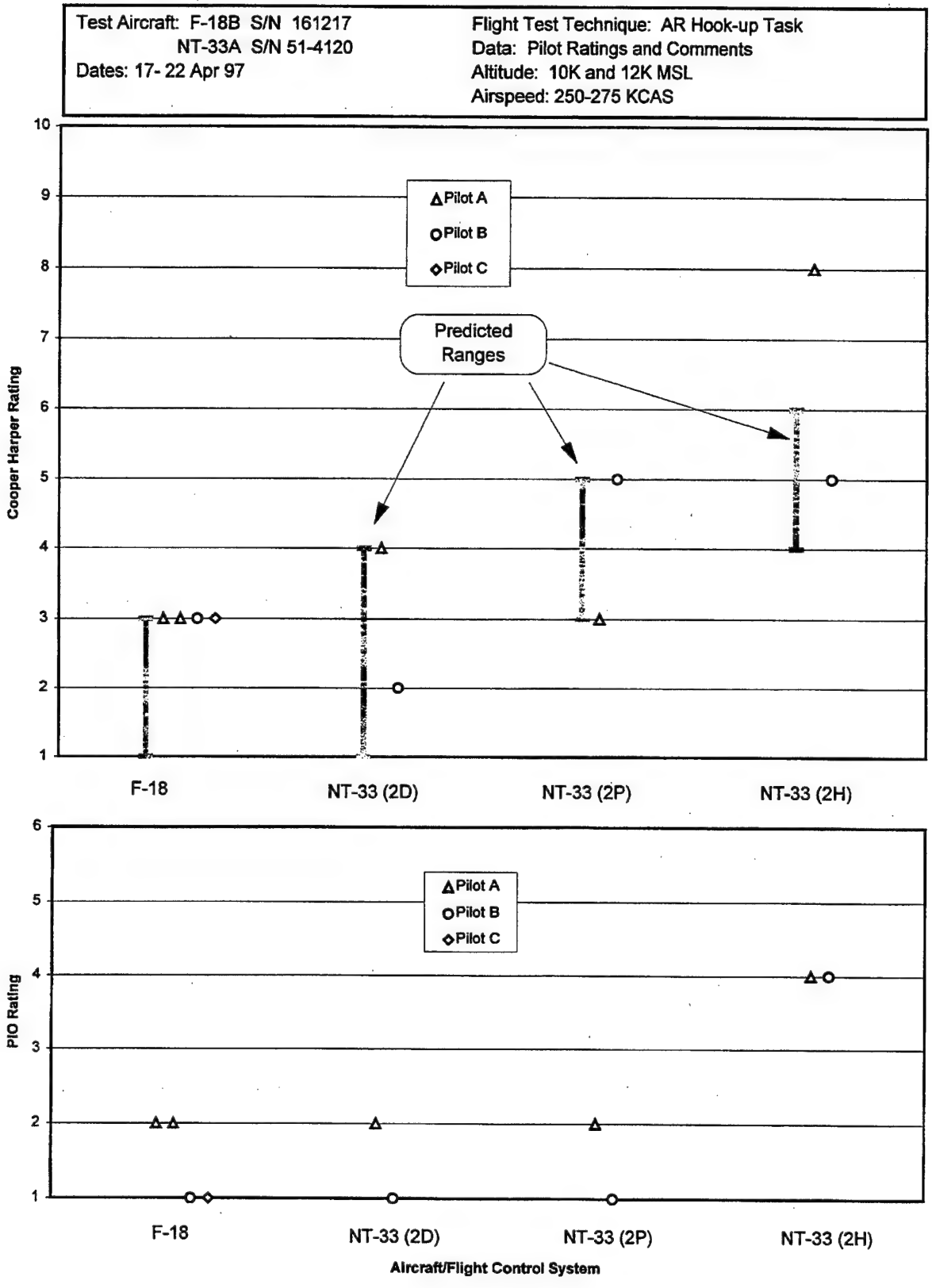

Figure C1 AR Hookup Task Results

TASK QUESTIONNAIRE						
Hookup Task	VERY	MODERATELY	SOMEWHAT	SOMEWHAT	MODERATELY	VERY
1. How well does maneuver represent operational probe and drogue refueling?	CLOSE			POOR		
Comments: "This task is the most operationally representative," "Lower point due to unacceptable aircraft flight control system"	■●◆ ■●	■	◆			
2. How well defined is the performance criteria? (quantifiable and measurable)	WELL-DEFINED			POORLY-DEFINED		
Comments: "Could account for turbulence"	●●◆	◆■■ ■				
3. How easy was it to tell if you were meeting the desired/adequate performance criteria?	EASY			HARD		
Comments: "I had no trouble telling whether I met the desired critieria," "Webbing criteria easy to see"	●●■	■■	◆■			
4. How would you rate the difficulty of achieving the performance criteria? How would you change it?	EASY			HARD		
Comments: "Avoiding the webbing makes task more difficult," "Somewhat difficult because air refueling is inherently a difficult task"		■	◆◆ ■	●■●		
5. For tracking task, how would you rate the distance from the basket? What is a better distance?	CLOSE			FAR		
Comments: N/A						
6. How is the duration of the task? What should it be?	SHORT			LONG		
Comments: N/A						
7. How would you assess your gain?	HIGH			LOW		
Comments: "Gain increased right before hookup," "Level of aggressiveness is clear and unambiguous for the task," "Could be flown low gain/open loop," "Slower closure rates caused gain to increase and made it more like the tracking task"			◆	◆■● ■	■●	
8. What was your confidence in assigning a CH rating?	HIGH			LOW		
Comments: "Easy to tell meeting criteria," "Confidence slightly lower in turbulence"	◆■	■●◆	●	■		
9. Assess your overall worth of task?	SATISFACTORY			UNSATISFACTORY		
Comments: "Has operational significance," "Could fly open-loop if the aircraft has a poor flight control system," "Faster closure rate allows for less need to track basket," "Somewhat unsatisfactory for evaluating closed-loop handling qualities"	◆	◆■● ■●■				

■ Pilot A
● Pilot B
◆ Pilot C

Figure C2 Hookup Task Questionnaire Results

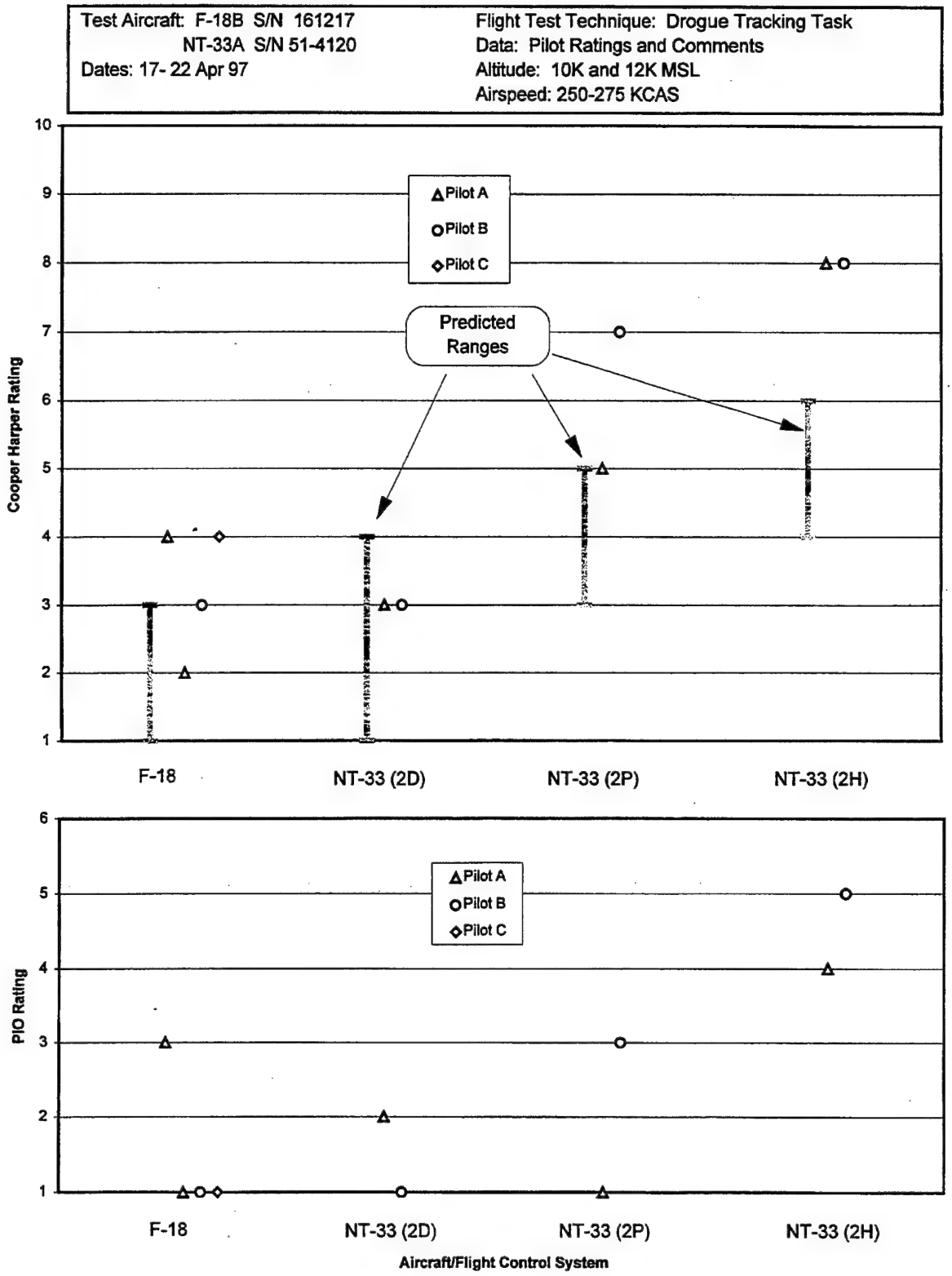

Figure C3 Drogue Tracking Task Results

TASK QUESTIONNAIRE						
Drogue Tracking Task	VERY	MODERATELY	SOMEWHAT	SOMEWHAT	MODERATELY	VERY
1. How well does maneuver represent operational probe and drogue refueling?	CLOSE			POOR		
Comments: "Resembles getting stable prior to a hookup attempt," "Represents lining-up portion"		●●	◆■■ ■			
2. How well defined is the performance criteria? (quantifiable and measurable)	WELL-DEFINED			POORLY-DEFINED		
Comments: "I did not have any trouble telling whether I was getting desired or adequate performance; however, it was up to pilot judgment to discern where 1/2-basket radius was"	●●	■■■	◆			
3. How easy was it to tell if you were meeting the desired/adequate performance criteria?	EASY			HARD		
Comments: "Difficult to tell how close you are without a chase aircraft," "Probe placement skews view," "Momentary deviations of basket--not sure if basket or pilot"	■■	●	■●	◆		
4. How would you rate the difficulty of achieving the performance criteria? How would you change it?	EASY			HARD		
Comments: "With a bad aircraft, pilot could not track at the close distances"	■		■	■◆	●●	
5. For tracking task, how would you rate the distance from the basket? What is a better distance?	CLOSE			FAR		
Comments: "Tracking distance was varied from 3 to 15 feet. Distance was optimized for 6 to 10 feet depending on probe placement on aircraft," "Very close at 6 feet, uncomfortably close at 3 feet"	●		◆■	◆		
6. How is the duration of the task? What should it be?	SHORT			LONG		
Comments: "20 seconds seemed short, especially if there were momentary deviations. Tracking longer will help to see if it occurs regularly," "Possibly use longer time and a percentage within range for the performance criteria"			●●◆	◆■■	■	
7. How would you assess your gain?	HIGH			LOW		
Comments: "With no basket motion, tracking was very easy with the F-18," "Turbulence caused higher gains especially at closer tracking distances"		◆	●●■	■	■	
8. What was your confidence in assigning a CH rating?	HIGH			LOW		
Comments: "If the basket did not move at all during the tracking time, the task became lower gain"	●	◆●■	■	■		
9. Assess your overall worth of task?	SATISFACTORY			UNSATISFACTORY		
Comments: "Best task for evaluating closed-loop handling qualities," "Not adequate in turbulence," "Pilot could distinguish between all three flight control systems using this task"	●●	◆■■	■			

■ Pilot A
● Pilot B
◆ Pilot C

Figure C4 Drogue Tracking Task Questionnaire Results

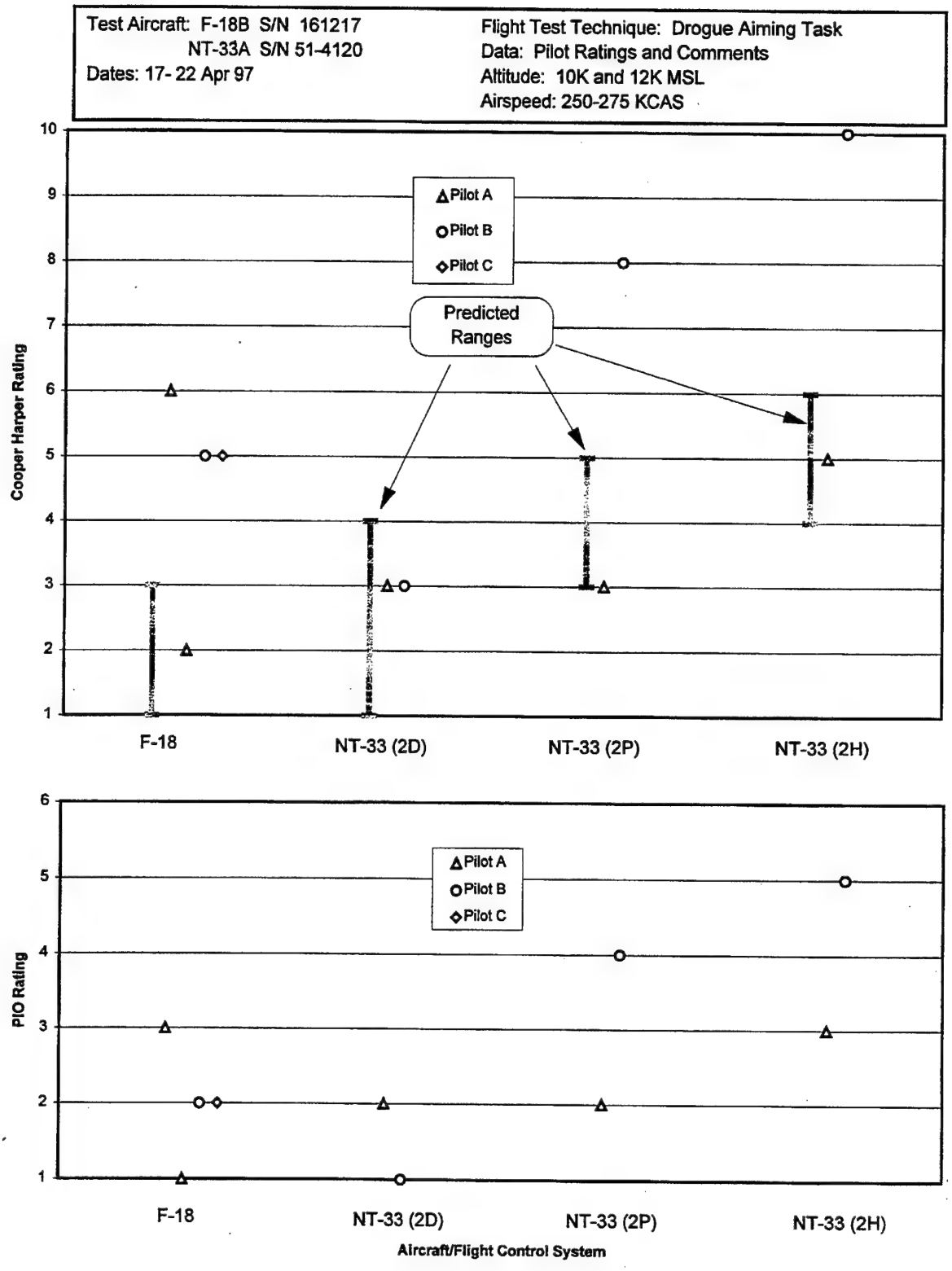

Figure C5 Drogue Aiming Task Results

TASK QUESTIONNAIRE						
Drogue Aiming Task	VERY	MODERATELY	SOMEWHAT	SOMEWHAT	MODERATELY	VERY
1. How well does maneuver represent operational probe and drogue refueling?	CLOSE			POOR		
Comments: "Only resembles last minute stab at drogue, but even then you wouldn't stop motion instantaniously," "More representative if done less aggressively"			◆■● ●■■			
2. How well defined is the performance criteria? (quantifiable and measurable)	WELL-DEFINED			POORLY-DEFINED		
Comments: "Probe placement on aircraft affected apparent basket size from top to middle to bottom," "Ratings changed when going from top to bottom or going from bottom to top"	●●	■	■■		◆◆	
3. How easy was it to tell if you were meeting the desired/adequate performance criteria?	EASY			HARD		
Comments: "Overshoots high would result in losing sight of the basket and no longer being able to tell distance," "Power effects detracted from task," "Too arbitrary," "Easy to tell with good aircraft and no turbulence"	■		■■● ◆	◆●	◆	
4. How would you rate the difficulty of achieving the performance criteria? How would you change it?	EASY			HARD		
Comments: "Very abrupt maneuver," "If can't stabilize on drogue, then can't even perform task," "Difficult to stailize when turbulent," "Turbulence caused basket to move faster than F-18 could track"			■■	◆■ ◆		●●
5. For tracking task, how would you rate the distance from the basket? What is a better distance?	CLOSE			FAR		
Comments: "Best distance with F-18 was 8 to 10 feet," "The closer the pilot was, the more potential of losing the basket if overshoots were high"	●		◆■			
6. How is the duration of the task? What should it be?	SHORT			LONG		
Comments: "5 second stabilizing seems long," "Long dwell time led to power effects due to wake turbulence"			■◆■	◆■● ●		
7. How would you assess your gain?	HIGH			LOW		
Comments: "Felt more like HQDT sometimes"		◆●●	■◆■	◆■		
8. What was your confidence in assigning a CH rating?	HIGH			LOW		
Comments: "Hard to tell performance versus basket motion"		◆■	■●◆ ■	●		
9. Assess your overall worth of task?	SATISFACTORY			UNSATISFACTORY		
Comments: "1/2-basket was a very small nose movement," "Overshoots hard to measure," "Lends itself to bad ratings," "Felt more like HQDT sometimes"		◆■■	●◆■	●		

■ Pilot A
● Pilot B
◆ Pilot C

Figure C6 Drogue Aiming Task Questionnaire Results

APPENDIX D

DAILY FLIGHT TEST REPORTS

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DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
NASA F/A-18B	NASA 161-217

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE GAS II	DATA FLT #2	21 APR 97
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
MAJ. SIZOO	11,000 lbs	M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
COL SMOLKA	38,000 lbs	CLEAR (WA 270/10; lt-mdt CAT sfc-8.0)
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
11:37/1.3	CENTERLINE TANK	Wnd 200/10 ; temp 80 PA 2240
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
T-38	Capt Meyers/ Capt Nelson	11:38/1.3

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of this flight was to investigate probe and drogue aerial refueling tasks for the evaluation of closed-loop aerial refueling handling qualities. This was done using both qualitative pilot comments and Cooper-Harper and PIO ratings. The test points were as follows:

- Formation take-off (with single seat NASA F/A-18)
- Rendezvous with S-3 tanker over Cal. City (10.0K 250 knots)
- Aerial refueling tasks (10.0 K 250 knots along chords road)
    - Practice F/A-18B aerial refueling hookups, drogue tracking, drogue aiming tasks
    - Hook-up task X 6
    - Tracking task X 3 (first two at 8 feet, last at 4 feet)
    - Aiming task X 3 (first two at 8 feet, last at 4 feet)

RTB to initial, Full Stop

5. RESULTS OF TESTS *(Continue on reverse if needed)*

HOOK-UP TASK X 6

A total of 6 hookups were attempted. Overall results were desired performance was achieved with 3 out of 6 hookups being successfully accomplished without the probe touching the drogue basket webbing. In addition to those 3 successful hook-ups, one hookup was successful with the probe contacting the webbing at right 1 o'clock, about 4 inches from target center; two hookup attempts were unsuccessful with one experiencing lateral oscillations. The chronological order of results follows:

Attempt #1: unsuccessful - oscillations encountered, gains up at end game, backed away
Attempt #2: successful hookup, webbing not touched, end game stab at center
Attempt #3: successful hook-up, webbing not touched, small lateral oscillations end game
Attempt #4: successful hook-up, webbing was touched, contacted 4 inches from center circle at 1 o'clock
Attempt #5: successful hook-up, webbing not touched
Attempt #6: unsuccessful hook-up, lateral oscillations, gains up at end game, backed away

For these 6 attempts pilot comments were: **CH 3, desired performance achieved with tolerable workload and minimal compensation. PIO 2, due to some undesirable lateral oscillations at end game. Control response was** **(continued on next page)**

6. RECOMMENDATIONS

1. Have chase film entire receiver aircraft (not just the probe). This way, the horizontal stabilator movement can be used to assess pilot gains and/or workload/compensation.
2. Adjust the tracking task distance to the point where performance drives the CH rating, not pilot assessment of workload (i.e., move the tracking task to 10-12 feet for the F-18). There was a inverse relationship between distance from the probe to the basket and the CH rating for the tracking task. At 8 feet desired performance was achieved but a level 2 HQ rating was assigned based on relative compensation. Expected results for the tracking task at 10-12 feet would be level 1 HQ ratings, consistent with the assumption of the F/A-18's HQR for probe and drogue (continued on last page)

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MAJOR DAVID G. SIZOO		18 Apr 97

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RESULTS OF TEST (Continued):

very predictable, and the initial response felt right. Bow wave effects were not a factor on these six attempts, however it was noted in practice that a slight bow wave effect was noticed when the drogue was approached from the side. Turbulence was minimal, causing some lateral basket oscillations, but nothing objectionable for task. The two unsuccessful hookup attempts were both terminated before 2 feet from drogue. On both of these the approach to the drogue resulted in a large offset (about 1 basket radius) which when attempted to null at about 3-4 feet distance resulted in pilot induced (nondivergent) oscillations due to high pilot gain at the terminal phase.

TRACKING TASK X 3

The tracking task was performed a total of 3 separate times. The first two tracking tasks were conducted at 8 feet and the third task was performed at 4 feet. The distances (from drogue to probe) were verified in flight by the chase aircraft using references on the aircraft for a distance yardstick. The tracking task was performed by visually aligning the probe with the bottom of the drogue (as opposed to projecting an imaginary extension of the probe to the basket) and tracking for 20 seconds. The bottom of the drogue was chosen to avoid the wake turbulence of the tanker aircraft. Two sets of CH and PIO ratings were given, one set for the task at 8 feet and one set for the same task at 4 feet.

For both drogue tracking tasks performed at **8 feet, desired performance** was achieved, however the **compensation was moderate** resulting in a **CH rating of 4.** It is important to note that the compensation level was assigned relative to the compensation given for the hookup task. In other words, the drogue tracking task at 8 feet required more compensation than the overall hookup task and was appropriately assigned a relatively higher level of compensation. For both drogue tracking tasks conducted at **8 feet, undesirable motions** in the pitch axes resulted when the pilot attempted tight control, resulting in a **PIO rating of 3**. These undesirable pitch oscillations could be seen from chase video. Again the PIO rating was assigned relative to the rating given for the hookup task. Note that some light turbulence was noted which did not affect pilot assessment of the task.

For the drogue tracking task conducted at **4 feet**, only **adequate performance** was achieved with **considerable compensation** resulting in a CH rating of 5. This compensation rating was assigned relative to all previous tasks. Note also that in my opinion, this distance was too close for the task. It felt like at the distance of 4 feet, even the best aircraft for aerial refueling would be driven to poor performance based on pilot gains going up. For the drogue tracking task performed at **4 feet, oscillations developed** in the pitch axis when **tight control** was initiated. This oscillation was **not divergent**, but I would have to **abandon the task** in order to recover. Consequently, the **PIO rating of 4** was assigned.

AIMING TASK X 3

The aiming task was performed a total of 3 separate times. The first two aiming tasks were conducted at 8 feet and the third task was performed at 4 feet. The distances (from drogue to probe) were verified in flight by the chase aircraft using references on the aircraft for a distance yardstick. The aiming task was performed by visually aligning the probe with an aim point on the drogue and then repositioning to a new aim point and holding for 5 seconds. It was discovered that making an aim point jump of 1 basket radius was too small and resulted in unwanted oscillations or a PIO due to overshooting the desired aim point. Furthermore, moving the probe from the bottom to the center of the basket resulted in an even larger PIO than moving from the center to the top. Consequently CH and PIO ratings were broken out by bottom to center aim point jumps and top to bottom aim point jumps. Some basket turbulence (light) was noted during the aiming tasks, but this did not interfere with task performance.

At **8 feet** and shifting aim point from the **bottom to the top** of the basket, **desired** performance was achieved but only with **considerable compensation**, resulting in a **CH rating of 5**. The **PIO** rating assigned was **3.** At **8 feet** and shifting the aim point from the **bottom to the center,** only **adequate performance** was achieved with **extensive compensation** resulting in a **CH rating of 6**. The PIO rating assigned was **5** since the oscillations were divergent with tight control unless I opened the loop.

At **4 feet** and shifting aim point from the **bottom to the top** of the basket, **desired** performance was achieved but only with **considerable compensation**, resulting in a **CH rating of 5**. The **PIO rating** assigned was **3.** At **4 feet** and shifting the aim point from the **bottom to the center,** only **adequate performance** was achieved with an **intolerable workload** resulting in a **CH rating of 8**. The **PIO** rating

RESULTS OF TEST (Concluded):

assigned was 5 since the oscillations were divergent with tight control unless I opened the loop. Note that there is less confidence in the CH and PIO ratings at 4 feet since these were assigned postflight due to mission time constraints.

RECOMMENDATIONS (Concluded):

3. Fly the tracking task at 10-12 feet aft for the reasons stated in recommendation 2. Continue moving the tracking task aft until the point at which the apparent size of the drogue makes the performance criteria meaningless.
4. Attempt the tracking task with a mark on the windscreen as a reference instead of the probe. That way, follow-on testing to define the best probe and drogue aerial refueling task to reveal AR handling qualities would not necessarily be limited to probe-equipped aircraft.
5. The hookup task results was very dependent on the approach set up (i.e., 8-12 feet away). Any references to line up at this distance resulted in a successful hookup.
6. Pilot gains increased successively for the hookup task, drogue tracking task, and aiming task (and CH and PIO ratings reflected this).
7. The F/A-18B was much easier to control in the hookup task than the practice sortie flown in the NT-33A. In fact, a slightly different technique was employed for the hookup task. In the NT-33A, the instructor taught us to <u>not</u> look at the basket during the end game (i.e., 3-6 feet). However, in the F/A-18B, the technique we were taught was to look at the basket throughout the approach and make any end game (i.e., 1-3 feet) directional corrections with rudder. Also, it seemed like less overtake was required with the F/A-18 (i.e., 2-3 knots vice 3-5 knots in the NT-33A) and an end game 'stab' at the basket (a last minute correction) was more productive in the F/A-18B versus the NT-33A.
8. For the aiming task, a 1 basket radius aim point jump was too small. A minimum of 1 basket diameter should be used when repositioning the probe.
9. Do not use the center of the basket as an aiming reference for the aiming task. It is easier to use a horizontal line across the top or bottom of the basket for an aiming reference.
10. The aiming task (using a basket diameter as an aim point jump) was not susceptible to distance. The same CH and PIO ratings were given at 8 and 4 feet.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
F/A-18B	161217

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE GAS II	DATA FLT #3	18 APR 97
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
Capt Latimer	11,000 lbs	M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
Mr Schneider	38,000 lbs	Clear
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1427/1.6	Center Line Tank	Dry / Winds 220/13G23 / 82°F
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
N/A	N/A	N/A

4. PURPOSE OF FLIGHT / TEST POINTS

To evaluate probe-and-drogue air refueling tasks for the HAVE GAS II test project. Test points consisted of performing Task 1/AR hook-up task, Task 2/tracking task at both 6 and 4 feet from the basket, and Task 2/aiming task at 6 feet from the basket. A short warm-up, consisting of low bandwidth tracking and 5 hook-ups, was performed prior to the test points. The support tanker was an S-3B from North Island NAS, CA. The tanker maintained 10,000-12,000 feet MSL and 250-275 KIAS.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Task 1/AR Hook-up: Performed at 10,000 feet MSL and 250-275 KIAS. Seven hook-up approaches were accomplished, with only 6 counted as attempts. The results were as follows:

1. Miss - low and right due to pilot chasing basket
2. Hook-up - hit webbing high and right
3. Miss - Turbulence moved basket, not counted as an attempt
4. Hook-up - no webbing
5. Hook-up - no webbing
6. Hook-up - no webbing, pilot made last minute correction down and right
7. Miss - high and right due to poor line-up

Desired performance was achieved (50% hook-ups without hitting the basket webbing), pilot workload was assessed as minimal to tolerable, and compensation was minimal. There were no undesirable motions or oscillations noticed.
CH Rating: 3
PIO Rating: 1
This task was mostly flown open-loop. I stabilized the aircraft with the probe about 8-10 feet from the basket and lined the probe up with the basket, then applied some power and drove straight into the drogue. Some attempts required almost no control stick inputs. I concentrated on looking at the buddy store and hose while keeping the basket in my peripheral vision. I made a concentrated effort not to chase the basket while driving in from 6 feet. Turbulence was only a factor on one attempt where the basket made a sudden move about 2 feet down and then back up, so this attempt was not counted. The worst turbulence seen was only light, and it did affect the task. No bow wave effects from the test aircraft were noticed. Wake turbulence from the tanker was felt and a couple clicks of left aileron trim were needed once I moved in behind the drogue. This did not affect the task.
The task was very operationally representative. I had no trouble telling whether I met the desired criteria. The criteria to not hit the webbing forced me to be very exact when doing the hook-ups, although I still did not feel that it was always a closed-loop task. Pilot gains were also moderately low, although gains did go up slightly right before the hook-up (about 1 or 2 feet from the basket). I had moderately high confidence in assigning a CH rating. Overall I felt that the task was somewhat unsatisfactory for evaluating closed-loop handling qualities, because it was flown open-loop and still attained desired performance.

6. RECOMMENDATIONS

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RESULTS OF TEST (Continued):

Task 2/Tracking Task

This task was performed three times, tracking for at least 20 seconds each time. The flight conditions were 10,000 feet MSL, 250-260 kts, no turbulence. The first and third tracking task attempts were performed with 6-8 feet distance from the probe tip to the edge of the basket, and the second attempt was performed with 4 feet of separation. No chase was available to confirm distances; it was based on both front and back seat pilots' judgment. Desired performance was achieved on all three attempts, no undesirable motions or oscillations were noted. The aircraft was very predictable and initial response was excellent. Constant stick inputs were required to keep the probe within ½ basket radius, but the aircraft response was quick and predictable which made desired performance attainable. Pilot workload was assessed as tolerable with minimal to moderate compensation when tracking at 6-8 feet. When tracking at 4 feet the number of stick inputs increased, and I felt much tenser on the controls. In this case, workload was assessed as tolerable, and compensation was between moderate and considerable.

CH rating: 3 (at 6-8ft) / 4 (at 4ft)

PIO rating: 1 (all attempts)

The task was definitely flown closed-loop. I had to concentrate on the probe tip and basket and make constant control inputs to keep the probe where I wanted it. I could tell that my gains were higher than during the hookup task, and my gains at 4 feet were higher than at 6-8 feet. It was more difficult to fly and talk in at 4 feet than it was at 6-8 feet. There was some effect from the tankers wake turbulence. In order to track the probe in the center of the basket, the aircraft was in a higher position relative to the tanker than when driving in for hook-ups, and I could feel some buffet on the aircraft from the wake turbulence. The result was that I had to make a power adjustment when stabilizing prior to beginning the 20 second tracking task. While tracking I still had to make some power adjustments to maintain a constant distance from the basket, but they were fairly small changes (1/8-1/4 knob width on the throttles). The placement of the probe prevented me from getting any closer than 4 feet because the probe is about 6 feet back from the nose, and the danger of striking the nose of the aircraft with basket increases when tracking inside of 6 feet. A tracking distance of 6-8 feet was better than 4 feet, because my gains were more representative of gains during the last portion of a hookup.

The task was moderately operationally representative, because it resembled lining the probe up with the basket prior to attempting a hook-up. I did not have any trouble telling whether I was getting desired or adequate performance, however it was up to pilot judgment to discern where ½ basket radius was. I felt that 20 seconds was somewhat short for tracking time. A longer time, maybe 30-45 seconds would be more appropriate to give the pilot more time to assess a handling qualities rating. In addition, if the basket did not move at all during the tracking time only minimal control inputs were necessary, and the task became more open-loop. I had moderately high confidence in assigning a CH rating. Overall, I thought the task was very satisfactory for evaluating closed-loop handling qualities.

Task 2/Aiming Task

The aiming task was performed 3 times at 6-8 feet distance from the probe to the edge of the basket. The flight conditions were 12,000 feet MSL, 250-270 KIAS, no turbulence (the tanker climbed up to 12,000 feet MSL to get out of and area of light turbulence in which the task could not be performed). I performed the task in the following manner: stabilized the probe in the middle of the basket, repositioned the probe to the top of the basket, stabilized there for 5 seconds, repositioned the probe to the bottom of the basket, stabilized there for 5 seconds, and finally repositioned the probe to the center of the basket and stabilized for 5 seconds. On the first attempt I was surprised by what a small movement this task required of the aircraft. Moving from the center to the top of the basket was the equivalent of moving the probe up only 2 probe-widths. I overshot the top of the basket by 1 radius (adequate performance), but was able to stabilize the probe within ½ radius of the top of the basket for 5 seconds. The movement from the top to the bottom of the basket was more manageable, and I got desired criteria, capturing the bottom of the basket within ½ radius and stabilizing for 5 seconds. When repositioning to the middle of the basket, I made a much smaller and slower control input than I did the first time and was able to capture the center of the basket within ½ radius. On the second attempt, I got desired criteria on all probe repositions, however I repositioned the probe fairly slowly and was out at 10-12 feet by the time I finished the maneuver due to tanker wake turbulence. On the third attempt, I got desired criteria on the first 2 probe repositions but overshot the center basket capture by 1 radius. Overall, I attained adequate criteria, assessed the workload

RESULTS OF TEST (Concluded):

as tolerable and compensation as moderate to considerable. When repositioning only 1 basket radius I noticed undesirable aircraft motions when tightly and abruptly controlling the probe position relative to the basket.

CH rating: 5

PIO rating: 2

This task was definitely a closed-loop task. It required constant control inputs and corrections to position the probe where I wanted it and to keep it there. However, the performance achieved is highly dependent on how aggressive the pilot is at repositioning the probe. On my first attempt I was fairly aggressive and the overshoot was a lot bigger than I anticipated. On subsequent attempts I made a conscious effort to make slower and more controlled inputs, but still overshot by a basket radius when doing the smaller (1 radius) reposition. In addition, wake turbulence from the tanker had an effect on maintaining a constant distance from the basket. The higher the test aircraft was relative to the tanker, the stronger the wake turbulence (noticed inside the cockpit by slightly increased buffet), and the higher the drag. Therefore, when repositioning the probe to the top of the basket the pilot had to make a slight power input to keep from falling back. With the requirement to stabilize at the top for 5 seconds, this became more critical. On my second task attempt the increased drag resulted in my sliding back to 10-12 feet half-way through the task. When repositioning to the bottom the reverse occurred. Wake turbulence decreased and drag decreased, so a power reduction was required to prevent moving in too close. The need for constant power changes increased pilot workload. Due to the proximity of the basket to the nose of the aircraft and the potential for overshooting the edge of the basket, I did not move in any closer than 6 feet.

The task was only somewhat operationally representative. It kind of resembled a last minute repositioning of the probe to engage a moving basket. However, when doing a last minute reposition to engage the drogue, the probe motion is not immediately stopped once the basket is engaged. The discernment of whether desired or adequate criteria was met was a little difficult when overshooting outside the basket, because I had to guess at what distance was ½ or a full basket radius. The desired criteria was very hard to attain and dependent on pilot technique and aggressiveness. The requirement to stabilize for 5 seconds after repositioning the probe was somewhat long, only because the longer I had to maintain different vertical positions the more effect the tanker's wake turbulence had on maintaining a precise distant from the basket. My gains were moderately high throughout the task and I had somewhat high confidence in assigning a CH rating. Overall, the task was somewhat satisfactory for evaluating closed-loop handling qualities.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
NT-33A	51-4120

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE GAS II	DATA FLT #4	21 APR 97
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
Capt Latimer	720 US gallons	M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
Mr Knotts	15,000 lbs	Clear
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1200/1.4	Clean	Dry / Winds 250/25G35 / 72°F
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
T-38A / 135	Maj Massucci / Capt Blatt	1200/1.6

4. PURPOSE OF FLIGHT / TEST POINTS

To evaluate probe-and-drogue air refueling tasks for the HAVE GAS II test project. Test points consisted of performing Task 1/AR hook-up task, Task 2/tracking task at 6 and 3 feet from the basket, and Task 2/aiming task at 6 feet from the basket. Three flight control configuration were flown: red, white, and blue. A short warm-up, consisting of low bandwidth tracking and 2 hook-ups, was performed prior to the test points using a different flight control configuration than the ones flown during test points. The support tanker was an S-3B from North Island NAS, CA. The tanker maintained 10,000-12,000 feet MSL and 250-275 KIAS.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

2H FCS CONFIGURATION

Task 1/AR Hook-up Task: A total of 7 approaches were made to the basket, and only 6 were counted as attempts. The flight conditions were 10,000 feet MSL, 250-260 KIAS, occasional light turbulence. The results of the attempts were:

1. hit (no webbing) - almost no stick inputs, flown open-loop, small PIO when disengaging
2. miss (low, center) - slight oscillation on run-in, hard to tell if it was me or the basket moving
3. miss (aborted attempt on run-in) - noticeable oscillations while approaching the basket
4. miss (aborted attempt on run-in) - basket moving up and down 3-4 feet due to turbulence, not counted as an attempt
5. hit (webbing low, left) - flown open-loop, very little control inputs
6. hit (webbing low, center) - open-loop, no stick inputs on run-in

Adequate performance achieved - 3/6 hook-ups, 2 hit basket webbing. I was unable to put in any last minute tight or abrupt corrections to the basket or an oscillation would develop (not divergent). However, if I had the probe lined up at about 8-10 feet out and the basket did not move, all I had to do was add power and drive straight in with little or no control inputs and I could engage the drogue. Workload was minimal. Compensation was assessed as moderate to considerable, because I had to make a conscious effort to make as few control inputs, and keep them as small as possible, to avoid getting into an oscillation. The aircraft response was fairly unpredictable and very sluggish. Oscillations developed when I attempted tight control and forced me to abandon the task.

CH rating: 5

PIO rating: 4

Task 2/Tracking Task: A total of three 20 second tracking tasks were performed at 6-8 feet distance (measured from the tip of the probe to the edge of the basket and confirmed by the chase aircraft). When I demanded tight control of the aircraft to keep the probe within the basket radius non-divergent oscillations would develop, and I would have to momentarily stop tracking the probe on the basket to recover. I could then begin tracking again trying to keep my gains as low as possible. I could not keep the probe within a basket radius of the center for a full 20 seconds. The best performance I could get was within a radius of the outside of the basket, and that was with occasionally abandoning the task and starting again. The aircraft response was somewhat unpredictable, very sluggish and the stick felt heavy. No attempt was made to track inside of 6 feet.

CH rating: 8

PIO rating: 4

6. RECOMMENDATIONS

COMPLETED BY	SIGNATURE	DATE
KELLY J. LATIMER, CAPT, USAF		23 APR 97

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RESULTS OF TEST (Continued):

Task 2/Aiming Task

I could not even begin this task, because I could not stabilize the probe within a basket radius without getting into a pitch oscillation. On this task, to get started I tried to force tight control even when an oscillation developed. The result was that I had to freeze the stick to recover. The task was attempted at 6-8 feet (distance confirmed by a chase ship).

CH rating: 10

PIO rating: 5

2D FCS CONFIGURATION

Task 1/AR Hook-up Task:

Only 4 attempts were made due to time constraints in completing all 3 FCS configurations. I was able to confidently assign CH and PIO ratings after the 4 attempts. The flight conditions were 10,000 feet MSL, 250-260 kts, and no turbulence. The results were as follows:

1. Hit (no webbing) - very small stick inputs during run-in
2. Hit (no webbing) - very little stick input until very end (about 1-2 feet from basket), made a quick movement of the probe to engage the drogue without hitting the webbing
3. Hit (no webbing) - was able to make constant small inputs to line the probe up with the center of the basket throughout run-in
4. Hit (no webbing) - had no problem flying the probe right smack into the middle of the basket

Desired performance was achieved with 4/4 hook-ups without hitting the webbing. I could fly these approaches more closed-loop than the previous configuration, and fly the probe to exactly where I wanted it to hit the basket. I was making very small stick inputs to control the probe position during most of the run-ins. Workload was minimal and pilot compensation was not a factor. No undesirable motions were noticed, and the aircraft's response was quick, predictable and very controllable.

CH rating: 2

PIO rating: 1

Task 2/Tracking Task

The tracking task was performed 3 times for 20-30 seconds each time and at a distance of 6-8 feet twice and 4-6 feet once (distance confirmed by a chase ship). The flight conditions were 12,000 feet MSL (the tanker climbed up from 10,000 feet MSL to get out of light to moderate turbulence), 250-265 kts, and no turbulence during the tracking task. While in an area of light turbulence I could not perform the task because the basket and tanker were moving too much. Once out of the turbulence, I stabilized at 10-20 feet behind the drogue before beginning the maneuver. I tried to tracked the probe onto the center of the basket. Desired performance was achieved on all three attempts. I was able to keep the probe within ½ basket radius of the center of the basket with only one or two momentary deviations due to basket motion. I felt that I could maintain very tight control of the probe's position relative to the basket, and there were no undesirable motions. I had to make continuous stick inputs, and felt that my gains were somewhat high. There was no difference in task performance between tracking at 6-8 and 4-6 feet except that my gains were slightly higher at 4-6 feet.

CH rating: 3

PIO rating: 1

Task 2/Aiming Task

The aiming task was performed 3 times total; at a distance of 6-8 feet twice and 4-6 feet once (distance confirmed by a chase ship). The flight conditions were 12,000 feet MSL, 250-260 kts, an no turbulence. I performed the task by stabilizing the probe in the center of the basket, repositioning it to the top of the basket, stabilizing there for 3 seconds, repositioning the probe to the bottom of the basket, stabilizing there for 3 seconds, then repositioning the probe to the center of the basket. Although the task description called for a 5-second stabilization at each end of the basket, I felt that 3 seconds was long enough for me to tell how precisely I could aim the probe where I wanted it, and I was short on time to complete all 3 FCS configurations. On the first attempt I overshot the top of the basket by 1 radius, because I repositioned the probe too fast. On that attempt, I achieved desired performance (aiming the probe within ½ basket radius of the desired position) when repositioning the probe to the bottom and center of the basket. On the last 2

RESULTS OF TEST (Continued):
attempts I repositioned the probe slower than on the first attempt, concentrating on not being too abrupt with my control inputs to avoid an overshoot of more than ½ basket radius. I achieved desired performance on the other 2 attempts at the task. Again, the aircraft response was very quick and predictable, and the stick felt fairly light. No undesirable motions were noted. When I attempted to do this maneuver at 4 feet, I slid back to about 6-8 feet by the time it was completed due to wake turbulence effects from the tanker, which increased as the test aircraft was moved to a higher position relative to the tanker. In addition, when repositioning the probe to the top of the basket and overshoot could result in losing some or all sight of the basket behind the aircraft nose, which was extremely uncomfortable inside of 6 feet. Small basket motion can also result in losing sight of the basket behind the nose when tracking the top of the basket. Therefore, I was very hesitant to increase power to overcome wake turbulence drag when tracking the top of the basket.
CH rating: 3
PIO rating: 1

2P FCS Configuration
Task 1/Hook-up Task

A total of 6 attempts were made. Flight conditions were 12,000 feet MSL, 250-270 kts, no turbulence. The results were as follows:

1. Miss (low/center) - good line up, but made a last second correction to try and hit the center of the basket which resulted in overshooting the entire basket
2. Miss (high/center) - good line up, but again chased center of the basket from about 2 feet out to try and hit the center and overshot the basket entirely
3. Hit (no webbing) - opened the loop on this one and did not chase the center of the basket, concentrated on looking at the buddy store and hose only keeping the basket in my peripheral vision
4. Hit (webbing on right) - remained open-loop on run-in, very few stick inputs and accepted position at the end instead of trying to make a jab for the middle
5. Hit (webbing high/center) - almost no stick inputs on run-in
6. Hit (webbing low/left) - same comments as on previous 2 attempts

Adequate performance was attained with 4/6 hook-ups with 3 hitting the basket webbing. On the first 2 attempts I was trying to hit the center of the basket and was not able to control the probe position quick or precise enough to do it, and ended up missing the basket altogether. On the next 4 attempts I stopped trying to force the probe into the center of the basket and concentrated on looking at the buddy store and hose, keeping the basket only in my peripheral vision. I accepted hitting the webbing during drogue engagements because I felt that a last minute stab for the center would result in a miss. The aircraft response did not seem to be sluggish or unpredictable, and I couldn't tell why I wasn't able to control where I hit the basket as well as I did with the white configuration. Workload was minimal to tolerable, and pilot compensation was minimal to moderate. I found it hard to assign a PIO rating because I never really demanded tight control other than at the end of the first 2 attempts which resulted in missing the basket. I did not think there were undesirable motions present even though I missed the target. The rest of the attempts were mostly open-loop.
CH rating: 5
PIO rating: 1

Task 2/Tracking Task

Three attempts to track were performed for 20 seconds minimum at a distance of 6-8 feet (distance confirmed by a chase ship). Flight conditions were 12,000 feet MSL, 250-260 kts, no turbulence. I tried to tracked the probe onto the center of the basket. On the first attempt I was able to track the probe within 1 basket radius of the center. However, the basket remained almost stationary while I was tracking, so I did not have to put in many control inputs. On the second attempt the basket did move, and I could tell that I was forced to work harder to track the basket precisely. On this attempt I noticed that the aircraft response was sluggish, and the stick felt a little heavier than before. I also noticed some undesirable motions when tracking tightly. There were momentary deviations outside of adequate performance (the probe tip went outside of 1 basket radius of the center) that were due to control inputs and not just basket motion. The third attempt had the same results as the second. Overall, I assessed that adequate performance was not achieved, because I could not keep the probe within the basket radius for the entire 20 seconds. Some of the

RESULTS OF TEST (Continued):
momentary deviations were due to basket motion (I did not count these in assessing performance), but others were due to control inputs (occasional undesirable motions due to tight and abrupt control inputs). Pilot workload was tolerable and compensation was considerable to extensive. I had to take into account a slight delay in aircraft response and consciously keep gains low to prevent undesirable motions from occurring.
CH rating: 7
PIO rating: 3

Task 2/Aiming Task

Three attempts at the aiming tasks were performed at 6-8 feet (distance confirmed by a chase ship). The flight conditions were 12,000 feet MSL, 250-260 kts, no turbulence. The aiming task was performed the same as with FCS white, except that I did not move inside of 6 feet because it was too uncomfortable. On all 3 attempts adequate performance was not achieved due to overshooting the desired aim point by more than 1 basket radius. Even while trying to stabilize after an overshoot I got into a small oscillation on 2 occasions and had to momentarily abandoned the task. The aircraft response felt sluggish and somewhat unpredictable when trying to precisely and quickly reposition the probe.
CH rating: 8
PIO rating: 4

OVERALL ASSESSMENT OF AR TASKS

Task 1

The maneuver was very operationally representative and the task criteria was well-defined. I had no problem telling whether or not I met the desired or adequate criteria. The only difficulty was determining whether basket motion was due to the basket moving or the test aircraft moving up and down, because a movement of 2-3 feet made a huge impact on the task. The desired criteria was moderately hard to achieve and adequate performance was somewhat hard to achieve. The criteria to not hit the webbing helped me to differentiate the White FCS from the Red and Blue. I could precisely drive the White FCS into the center of the basket and could not with the Blue or Red. My gains were somewhat low during this task but increased slightly as distance from the basket decreased less than 3 feet. I had somewhat high confidence in assigning a CH rating. The rating was assigned mostly on performance since workload was always minimal or minimal to tolerable, and compensation was only noticed on the Red FCS. It was hard to assign a PIO rating because a lot of the time I could fly the hook-ups open-loop. It was somewhat unsatisfactory for evaluating closed-loop handling qualities because it can be flown somewhat or completely open-loop.

Task 2/Tracking Task

This task is moderately representative of operational probe-and-drogue, because it resembles lining the probe up with the basket prior to running-in for a hook-up (although done more precisely in this task). The performance criteria was well-defined. It was up to pilot judgment to discern where ½ basket radius was, but this was not too difficult. However, the probe on the NT-33 is up in front of the pilot and slightly above the nose so the full basket was in view the entire time and it was in the shape of a circle. Had the probe been further to the side or displaced more up or down the view of basket would be skewed and these references may be harder to tell. The only difficulty I had in assessing whether desired or adequate performance was achieved was how to count momentary deviations that were not due to basket motion (came into play for the Blue FCS). The tracking distance of 6-8 feet seemed very close which kept my gains somewhat high. When moving in to 3-4 feet, the distance was uncomfortably close, and harder to maintain. The 20 second duration was somewhat short, especially if there was basket motion. A longer time I think would have made it easier to distinguish what was basket motion and what was aircraft motion. The performance criteria was moderately hard to achieve. I had very high confidence in assigning a CH rating on all FCS except for how to handle momentary deviations with the Blue FCS. I also had very high confidence in assigning a PIO rating. I felt that I could distinguish between all three FCS with this task. This task was very satisfactory for evaluating closed-loop handling qualities.

RESULTS OF TEST (Concluded):

Task 2/Aiming Task

This maneuver only somewhat represents operational probe-and-drogue AR. It resembles a last minute correction to the drogue when hooking-up. But even when a last minute correction is made, the upward or downward motion is not immediately stopped as this task required. The performance criteria was very well-defined, but it was somewhat hard to tell if the criteria was met. Overshoots outside of the basket were hard to judge for distance from the basket, especially overshoots above the basket, where the basket can disappear from view behind the nose of the aircraft. It was very hard to achieve the desired and adequate criteria. The maneuver was fairly abrupt, and my aggressiveness at repositioning the probe had a huge impact on the performance achieved. If I was very aggressive, an overshoot of 1 basket radius was inevitable with any of the FCS. There also was no point in attempting this maneuver with a FCS that could not attain desired performance with the tracking task. If I could not stabilize the probe within ½ radius of the center, then it was impossible to do this task and accurately assess performance. A distance of 6-8 feet was very close and any closer was very uncomfortable, especially since overshoots were so prevalent in this maneuver. There was no need to stabilize for more than 2-3 seconds before repositioning the probe. The longer the time spent at different vertical positions on the tanker, the more drag from wake turbulence effected the task. My gains were moderately high during this task. I had somewhat low confidence in assigning a CH and PIO ratings. Since the distance to reposition the probe was very small, the criteria seemed extremely tight. This task was somewhat unsatisfactory for evaluating close-loop handling qualities.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
NT-33A	51-4120

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE GAS II	DATA #6	21 APR 97
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
MAJ. SIZOO	720 US gallons	M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
LOU KNOTTS	15,000 lbs	lt-mdt CAT sfc-8.0)
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1445 /1.6	CLEAN	Dry / Winds 250/25G35 / 83°F
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
T-38	Maj Masucci/ Capt O'Connor	1445/1.6

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of this flight was to investigate probe and drogue aerial refueling tasks for the evaluation of closed-loop aerial refueling handling qualities. This was done using both qualitative pilot comments and Cooper-Harper and PIO ratings. The test points were as follows:

-Take-off (with chase 20 sec)
-Rendezvous with S-3 tanker over Cal. City (10.0K 250 knots)
-Aerial refueling tasks (10.0 K 250 knots, 4 miles north of chords road, climbed to 12.0 K for turbulence)
- Practice NT-33A aerial refueling hookups, drogue tracking, drogue aiming tasks
  FCS Red (2D - Good):
    Hook-up task X 6
    Tracking task X 3 (6 feet,3 feet,10 feet)
    Aiming task X 3 (6 feet,3 feet,10 feet)
  FCS White (2H - Bad):
    Repeat above 3 lines
  FCS Blue (2P - Medium)
    Repeat above 3 lines
- Step inputs
- RTB to initial, Full Stop

5. RESULTS OF TESTS *(Continue on reverse if needed)*

OVERALL COMMENTS and CONCLUSIONS

The confidence in Cooper-Harper and PIO ratings was low due to turbulence. We need to use a different turbulence scale that accounts for basket motion on individual tasks. The turbulence scale that we used described aircraft motion, and by that scale, there was minimal to light turbulence. However, most tasks today were performed with conditions of a lot of basket motion (i.e., movements of 2 basket diameters) and only a couple of tasks were performed with a relatively stable basket (at the western edge of the track, near Tehachapi). This unpredictable basket motion, while operationally relevant, most definitely affected both task performance and workload, and was not consistent for all the tasks today.

If you had to perform all three tasks under the same environmental conditions as today, it seemed like the AR hookup task was least effected by the turbulence. If turbulence was a factor on a hookup attempt, you could discount that attempt and "reset" pilot gains. If turbulence was a factor for the tracking or aiming tasks, it would just drive up pilot gains or cause more and higher frequency pilot inputs. For many of the tracking and aiming tasks, it was impossible to hold the basket for the required time within desired criteria with the good flight control system if basket motion due to turbulence was a factor. The AR hookup task is a shorter duration task and could still be accomplished with some basket motion.

The AR hookup task differentiated between the good/medium FCS and the bad FCS.

6. RECOMMENDATIONS and CONCLUSION

1. Use a turbulence scale based on basket motion and how it effects the individual tasks

COMPLETED BY	SIGNATURE	DATE
MAJOR DAVID G. SIZOO		21 APR 97

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RESULTS OF TEST (Continued):

FCS RED (2D - GOOD A/C)

HOOK-UP TASK X 6

A total of 6 hookups were attempted. Overall results were desired performance was achieved with 3 out of 6 hookups being successfully accomplished without the probe touching the drogue basket webbing. In addition to those 3 successful hook-ups, one hookup was successful with the probe contacting the webbing due to basket motion; 2 hookup attempts were unsuccessful with the probe missing at the 12 o'clock position on the basket. The chronological order of results follows:

Attempt #1: successful hookup, webbing not touched, (contact with center ring at 1 o'clock)

Attempt #2: unsuccessful hookup, contacted basket edge at 12 o'clock, probably due to turbulence at end

Attempt #3: unsuccessful hook-up, probe ½ way up basket - no contact, turbulence NOT a factor

Attempt #4: successful hook-up, webbing not touched

Attempt #5: successful hook-up, webbing touched, but touch discounted due to turbulence

Attempt #6: successful hook-up, webbing not touched

CH 4 was assigned, desired performance achieved with tolerable workload and moderate compensation. Note that turbulence was an issue and drove the compensation level from minimal to moderate. Also, the compensation was higher than that required for the F/A-18 hookup task. PIO 2, undesirable motions eliminated by pilot technique (lowering gains, not looking at basket, and keeping a high closure rate of 5 knots)

Overall the task is well defined. Confidence in ratings was low due to corruption by turbulence. Pilot gains were medium to low. Note that with stagnation or slowing the rate of closure from 5 knots results in pilot gains going up or likens this task to the aiming task.

TRACKING TASK X 3

The tracking task was performed a total of 3 separate times for 20 seconds each, once at 6 feet, then at 3 feet then at 10 feet.

For the drogue tracking task performed at **6 feet and at 10 feet, desired performance** was achieved, with **minimal compensation** resulting in a **CH rating of 3.** This compensation was less than that required for the AR hookup task. **PIO** rating assigned for tracking at 6 feet and 10 feet was **2.**

For the drogue tracking task performed at **3 feet**, desired performance was not attained **due to basket motion and turbulence**. Only adequate performance was achieved and compensation level was extensive due to pronounced turbulence effects and increased basket motion.

AIMING TASK X 3

The aiming task was difficult to perform since it required that the basket be stabilized before beginning. Turbulence prevented that in several attempts. The aiming task was performed 3 separate times with this flight control system at 6 feet, then 3 feet, then at 10 feet. Note that desired performance was achieved for all three distances and compensation required was minimal for the aiming task at all three distances. At 3 feet the basket jumped around more than it did at 10 feet (more turbulence? or geometry?) For all distances a CH rating of 3 was assigned with desired performance and minimal compensation was assigned along with a PIO rating of 2.

FCS WHITE (2H - BAD A/C)

It was noted during low bandwidth maneuvering that this configuration had very heavy stick forces

HOOK-UP TASK X 5

A total of 5 attempts were made. 4 were unsuccessful due to longitudinal oscillations, and 1 attempt was discounted due to basket motion at end game. The chronological sequence was:

Attempt #1: unsuccessful hookup, longitudinal oscillations

Attempt #2: unsuccessful hookup, undesirable longitudinal motions

Attempt #3: unsuccessful hook-up, basket motion (attempt discounted post-flight review of video tape)

Attempt #4: unsuccessful hook-up

RESULTS OF TEST (Continued):

Attempt #5: unsuccessful hook-up

Attempt #6: not flown - FCS could be assessed already

Less than adequate performance was achieved and considerable pilot compensation was required to maintain control, particularly at end game, inside of 3 feet. Consequently a CH of 8 was assigned. The very heavy stick forces resulted in pilot pitch inputs getting out of phase with aircraft response. The oscillations encountered did not result in a divergence, but the task had to be abandoned in order to recover from the oscillations. Consequently a PIO rating of 4 was assigned.

TRACKING TASK X 2

Adequate performance could not be realized at 6 feet, so no attempt was made at 3 feet. Likewise, adequate performance could not be achieved at 10 feet either. For the same reasons as the hookup task, CH of 8 and PIO of 4 were assigned.

AIMING TASK X3

Smooth air was encountered for this particular task and CH ratings (performance driven) reflect this. The aiming task was performed at 6, 3, and 10 feet and the results were the same at all distances. Adequate performance was achieved (within 1 basket radius) if the initial overshoot was discounted. The aiming order was bottom of basket, top of basket, bottom of basket then middle Adequate performance with considerable compensation resulted in a CH rating of 5. Undesirable motions prevented by considerable pilot effort resulted in a PIO of 3 being assigned. Note that the relatively good CH and PIO ratings are probably due to smooth air (relative to the 2 previous tasks).

FCS BLUE (2P - MEDIUM A/C)

HOOK-UP TASK X 6

A total of 5 attempts were made with this flight control system. 4 of the 5 were successful without touching the webbing, 1 was successful with touching the webbing, (and 1 attempt was discounted due to turbulence.) The chronological order is as follows:

Attempt #1: successful hookup, did not touch webbing

Attempt #2: attempt discounted (post flight video review) due to turbulence

Attempt #3: successful hook-up, did not touch webbing

Attempt #4: successful hook-up, did not touch webbing

Attempt #5: successful hook-up, did not touch webbing

Attempt #6: successful hook-up, did touch webbing at 6 o'clock

Note that desired performance criteria was meet. During all 6 hookup attempts with 2P, it was noted that turbulence was less than during the 6 hookup attempts with 2D. Consequently, pilot compensation (minimal) was less than with configuration 2D and a CH rating of 3 was assigned. A PIO rating of 2 was assigned. Note that at this point in the air, I thought this FCS was the best, but there was less turbulence present for this task.

TRACKING TASK X 3

The tracking task was attempted at 6, then 3, then 10 feet. Note that turbulence for this task was more than the AR hookup task for the same FCS. At 6 feet desired performance was achieved. At 3 feet only adequate performance was achieved. At 10 feet turbulence (basket motion) resulted in only adequate performance. An overall CH rating of 5 was assigned for the 6 feet distance due to perceived considerable pilot compensation. Again, this perceived compensation level could be the result of turbulence. Since there was never a tendency for undesirable motions, a PIO rating of 1 was assigned.

AIMING TASK X 3

The aiming task was attempted at 6, then 3, then 10 feet. At 6 and 3 feet desired performance was achieved with minimal compensation, resulting in a CH rating of 3. Turbulence did cause some basket motion which in turn caused some undesirable aircraft motion with tight pilot control. However, this undesirable motion could be eliminated with pilot technique. Consequently, a PIO rating of 2 was assigned. The aiming task performed at 10 feet was inconclusive since basket motion due to turbulence was too great.

RECOMMENDATIONS (Concluded):

2. The AR hookup task does delineate between aircraft with bad and good/mediocre handling qualities
3. Given turbulent conditions with basket motion, the track and aim tasks were almost useless
4. Given turbulent conditions with basket motion, the AR hookup task was the best at revealing handling qualities
5. The confidence level assigned all CH and PIO ratings was very low due to basket motion and turbulence

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
F/A-18B	NASA 161-217

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE GAS II	DATA #7	22 APR 97
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
MAJ. SIZOO	11,000 lbs	M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
ED SCHNEIDER	38,000 lbs	CLEAR (lt-mdt CAT sfc-8.0)
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
13:53/2.2	CENTERLINE TANK	Wnd 260/10 ; temp 75 PA 2210
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
(SINGLE SEAT F/A-18)	Mr. Folsom ("Folger")	13:53/2.1

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of this flight was to investigate probe and drogue aerial refueling tasks for the evaluation of closed-loop aerial refueling handling qualities. This was done using both qualitative pilot comments and Cooper-Harper and PIO ratings. The test points were as follows:

-Formation take-off (with single seat NASA F/A-18)
-Rendezvous with S-3 tanker over W-291(10.0K 250 knots)
-Aerial refueling tasks (10.0 K 250 knots)
-- Practice F/A-18B aerial refueling hookups, drogue tracking, drogue aiming tasks
-- Hook-up task X 6
-- Tracking task X 3 (30 seconds, at 8 feet) (first one using tight performance criteria, next two with loose criteria*)
-- Tracking task X 3 (30 seconds, at 15 feet) (first one using tight performance criteria, next two with loose criteria)
-- Aiming task X 3 (6,12,3,9 o'clock at 8 feet) (first one using tight performance criteria, next two with loose criteria)
-- Aiming task X 3 (6,12,3,9 o'clock at 15 feet)(first one using tight performance criteria, next two with loose criteria)
-- Composite task at 8 feet (first tracking, then aiming then hookup attempts X3) (no performance criteria designed)
-RTB to Edwards

Note: distances from drogue to probe were verified by F/A-18 chase aircraft
*tight performance criteria was the same as before, desired - ½ basket radius, adequate - 1 basket radius
loose performance criteria was attempted with: desired - 1 basket radius, adequate - 1 basket diameter

5. RESULTS OF TESTS *(Continue on reverse if needed)*

OVERALL

1) The air over the water in W291 was extremely stable - turbulence was no factor today.

2) There was no noticeable difference in pilot gains with the loose performance criteria with the Level 1 F/A-18 for the tracking and aiming tasks. It would be interesting to fly a Level II aircraft with loose performance criteria to determine if the criteria is too loose. Desired performance criteria were met for the tracking and aiming tasks with loose criteria. (One noticeable difference was the lack of momentary excursions outside the loose criteria, especially since there was no turbulence today).

3) The tracking and aiming tasks were also performed at distances further back than done on the first F/A-18 data sortie: 15 feet and even out to 20 feet were attempted. The recommended distance for the tracking and aiming tasks is 8-12 feet. At 15-20 feet, the apparent size of the basket is too small in relation to the probe to be useful for accomplishing aiming or tracking.

6. RECOMMENDATIONS and CONCLUSION

1. Fly tracking and aiming tasks with loose performance criteria (desired =1 radius) with a level II aircraft
2. The recommended distance for the tracking and aiming tasks is 8-12 feet in the F/A-18.
3. The recommended best task would combine the tracking task and the hookup task.
4. Recommend not performing the aiming task at the 9 o'clock position on the basket.
5. Use only rudder for lateral corrections during aiming or the hook-up task.
6. The duration of the tracking task should be a minimum of 20-30 seconds.

COMPLETED BY	SIGNATURE	DATE
MAJOR DAVID G. SIZOO		22 APR 97

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RESULTS OF TEST (Continued):

4) Cooper-Harper and PIO ratings were better than the first F/A-18 data sortie for two apparent reasons. Pilot learning curve and smooth air with no basket motion.

5) Part of the learning curve for the hookup task involves the initial line up on an approach. Once the proper basket to probe apparent lateral offset for a given distance aft is learned, the set up aft of the drogue is simple. In fact, after a few hookups the basket less during approaches and merely monitor the "zeroing out" of the apparent lateral offset as the distance to the basket is closed.

6) Recommend a task combining the tracking task and the hook-up task. The tracking task could be performed at 8-12 feet as a build up approach prior to attempting any hookups. The tracking task forces the pilot to be closed-loop and may expose handling qualities which the hookup task wouldn't. However, the operational nature of the hookup task is also desired.

7) The aiming task was performed by starting at the 6 o'clock and moving to 12 o'clock as previously done. After 12 o'clock aiming was then attempted at 3 o'clock and 9 o'clock. Aiming at 9 o'clock for the ranges of 8 and 15 feet did not work well due to the basket geometry. The left half of the basket was obscured by the outer ring of the basket, and the basket radius used for performance criteria could not be seen easily. Recommend not doing the aiming task at the 9 o'clock position on the basket.

8) Power effects could be seen on the aiming task. When repositioning from 6 to 12 o'clock the F/A-18 would drop aft about 2-4 feet unless power was applied. This increased the workload on the aiming task.

9) The aiming task from 12 to 3 o'clock and last minute lateral corrections on the hookup task should be made with rudder vice ailerons. This prevents coupling in the vertical axis.

10) The duration of the tracking task was investigated. A minimum o f 20-30 seconds should be adequate to assess performance and compensation criteria. If turbulence or basket motion causes excursions, the pilot should track for a longer time until the handling qualities can be assessed.

HOOK-UP TASK X 6

A total of 6 hookups were attempted. Overall results were desired performance was achieved with 3 out of 6 hookups being successfully accomplished without the probe touching the drogue basket webbing. In addition to those 3 successful hook-ups, one hookup was successful with the probe contacting the webbing. The two unsuccessful hookups were lateral misses at the same clock position (9 - 10 o'clock). The chronological order of results follows:

Attempt #1: unsuccessful - missed at 9 o'clock
Attempt #2: unsuccessful - missed at 10 o'clock
Attempt #3: successful hook-up, webbing touched, small lateral end game correction
Attempt #4: successful hook-up, webbing not touched
Attempt #5: successful hook-up, webbing not touched
Attempt #6: successful hook-up, webbing not touched

For these 6 attempts pilot comments were: **CH 3, desired performance** achieved with tolerable workload and **minimal compensation. PIO 2,** due to some undesirable lateral oscillations at end game. Control response was very predictable, and the initial response felt right. Bow wave effects were not a factor on these 6 attempts. There seemed to be a learning curve after the first 2 attempts on this sortie. The tendency to use aileron for lateral corrections was corrected by attempts #4-6. The same overall comments apply as F/A-18 sortie #1. Success of the hook-up is greatly affected by the approach set-up.

TRACKING TASK X 3 at 8 feet

The tracking task was performed 3 times at 8 feet. The first one used the tight performance criteria and the next two used loose criteria. **Desired performance** was achieved with both criteria with not much noticeable difference in pilot gains. Note that there were momentary excursions seen with the ½ basket radius criteria that were not seen with the 1 radius criteria. These momentary excursions were discounted in assigning the ratings. **CH of 2** was assigned based on the fact that compensation relative to the hookup task was less (i.e., not a factor.) Note that on my F/A-18 sortie #1 the compensation level assigned to the tracking task was higher than the hookup task! This can be attributable to a learning curve for the task and an extremely stable basket on the 2nd F/A-18 sortie tracking task. On the 2nd F/A-18 sortie, I did not have to stay tightly in the loop with high pilot gains to just track the basket. Consequently the CH rating assigned to the tracking task was lower on the 2nd sortie (and lower than the CH rating assigned to the Hookup task.)

RESULTS OF TEST (Concluded):

After having seen the affects of turbulence on the NT-33A data sortie, it seems that turbulence affects CH and PIO ratings on the tracking task more than the AR hookup task. Pilot gains are driven up and remain up with the tracking task if there is any basket motion.

A **PIO** rating of 1 was assigned since there was no tendency to induce undesirable motions.

TRACKING TASK X 3 at 15 feet

The same series of tracking tasks was repeated at 15 feet as was done at 8 feet. The results were the same: **CH** of **2** and **PIO** of **1.** The best distance to perform the tracking task in the F/A-18 was determined to be about 8-12 feet based on the level of pilot gains at that distance.

AIMING TASK X 3 at 8 feet

The aiming task was performed 3 times at 8 feet, starting at the 6 o'clock position and moving to the 12 o'clock position, then 3 o'clock and finally 9 o'clock position on the basket. The first one used the tight performance criteria and the next two used loose criteria. **Desired performance** was achieved (with no pilot compensation) resulting in **CH** of **2.** The same rating was assigned with both criteria. There were no noticeable differences in pilot gains with this aircraft with the two different criteria. An overshoot resulted when ailerons were used to go from 12 to 3 o'clock. This overshoot did not occur when rudder was used.

A **PIO** rating of **1** was assigned since there were no tendencies to induce undesirable motions.

AIMING TASK X 3 at 15 feet

The same series of aiming tasks was repeated at 15" as was done at 8 feet. The results were the same: **CH** of **2** and **PIO** of **1.** The best distance to perform the aiming task in the F/A-18 was determined to be about 8-12 feet based on the level of pilot gains at that distance.

APPENDIX E

RATINGS SCALES

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COOPER-HARPER RATING SCALE

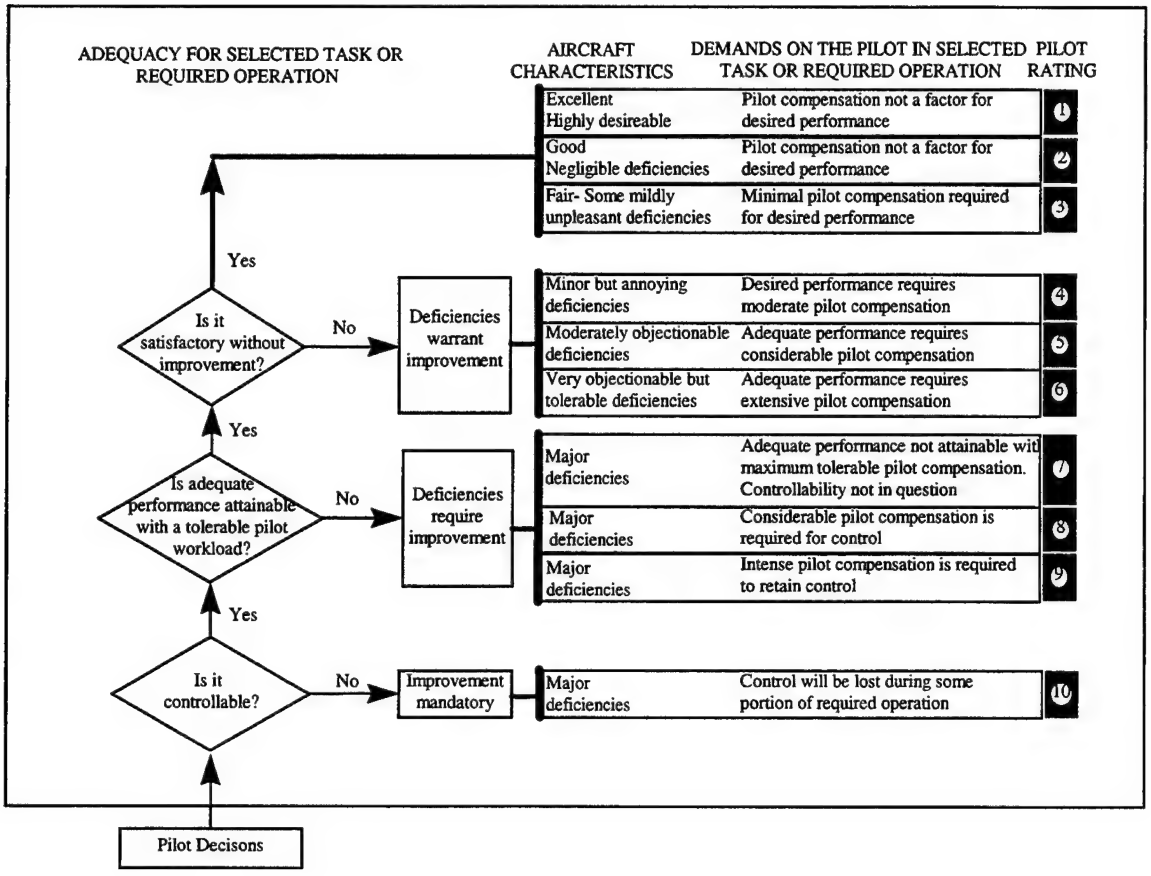
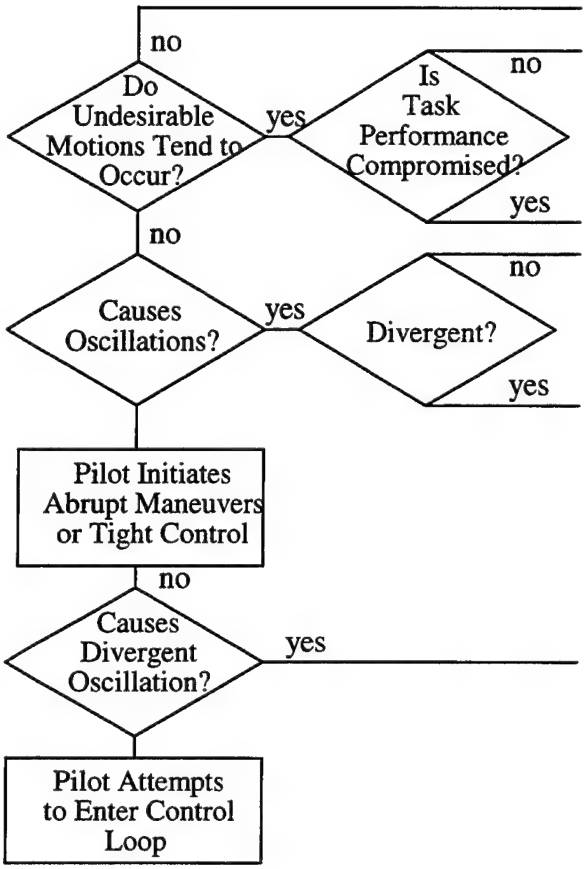


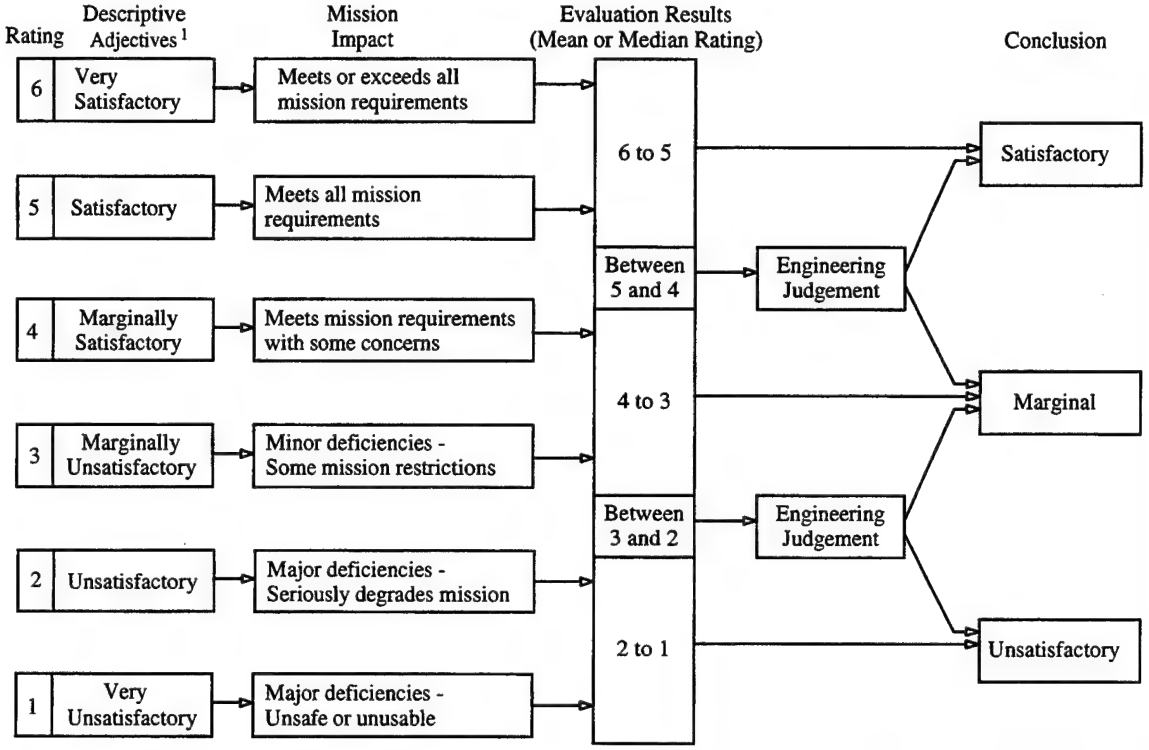
Figure E1 Cooper-Harper Rating Scale



	Description	Rating
1	No tendency for pilot to induce undesirable motions.	1
2	Undesirable motions tend to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.	2
3	Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort.	3
4	Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.	4
5	Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must open loop by releasing or freezing stick.	5
6	Disturbance or normal pilot control may cause divergent oscillation. Pilot must open control loop by releasing or freezing the stick.	6

Figure E2 Pilot-Induced Oscillation (PIO) Rating Scale

Evaluation Process When Using Subjective Data (Rating Scales)



[1]Alternative descriptive adjectives from the table below may be used to develop rating scales that are more appropriate to meet evaluation requirements.

Alternative Descriptive Adjectives

Rating Number	Modifiers	Rating Scale Base Wording Options				
6	Extremely Fully Completely Very	Satisfactory	Comfortable	Good	High	Like
5	None (Base word only) Moderately					
4	Marginally Slightly Somewhat					
3	Same as used for rating number 4.	Unsatisfactory	Uncomfortable	Poor	Low	Dislike
2	Same as used for rating number 5.					
1	Same as used for rating number 6.					

Figure E3 AFFTC Descriptor Evaluation Scale

ADJECTIVE CLASS	OPERATIONAL CRITERIA	DERIVED GUST VELOCITY
Light	Occupant requires seat belt, but unsecured objects in the cabin remain at rest.	5 - 20 ft/s
Moderate	Occupant requires seat belt and is occasionally thrown against the belt. Unsecured objects in the cabin move about.	20 - 30 ft/s
Severe	Aircraft may be out of control momentarily. Occupant is thrown violently against the belt and back into the seat. Unsecured objects in the cabin are tossed about.	35 - 50 ft/s
Extreme	Rarely encountered condition where aircraft is violently tossed about and is practically impossible to control. Structural damage may result.	> 50 ft/s

Figure E4 Turbulence Criteria Scale

INCREASE OF PILOT EFFORT WITH TURBULENCE	DETERIORATION OF TASK PERFORMANCE WITH TURBULENCE	RATING
NO SIGNIFICANT INCREASE	NO SIGNIFICANT DETERIORATION	A
MORE EFFORT REQUIRED	NO SIGNIFICANT DETERIORATION	B
	MINOR	C
	MODERATE	D
BEST EFFORTS REQUIRED	MODERATE	E
	MAJOR (BUT EVALUATION TASKS CAN STILL BE ACCOMPLISHED)	F
	LARGE (SOME TASKS CANNOT BE PERFORMED)	G
UNABLE TO PERFORM TASKS		H

Figure E5 Recommended Turbulence Effect Rating Scale (Reference 8)

APPENDIX F

TEST AND SUPPORT AIRCRAFT PHOTOS

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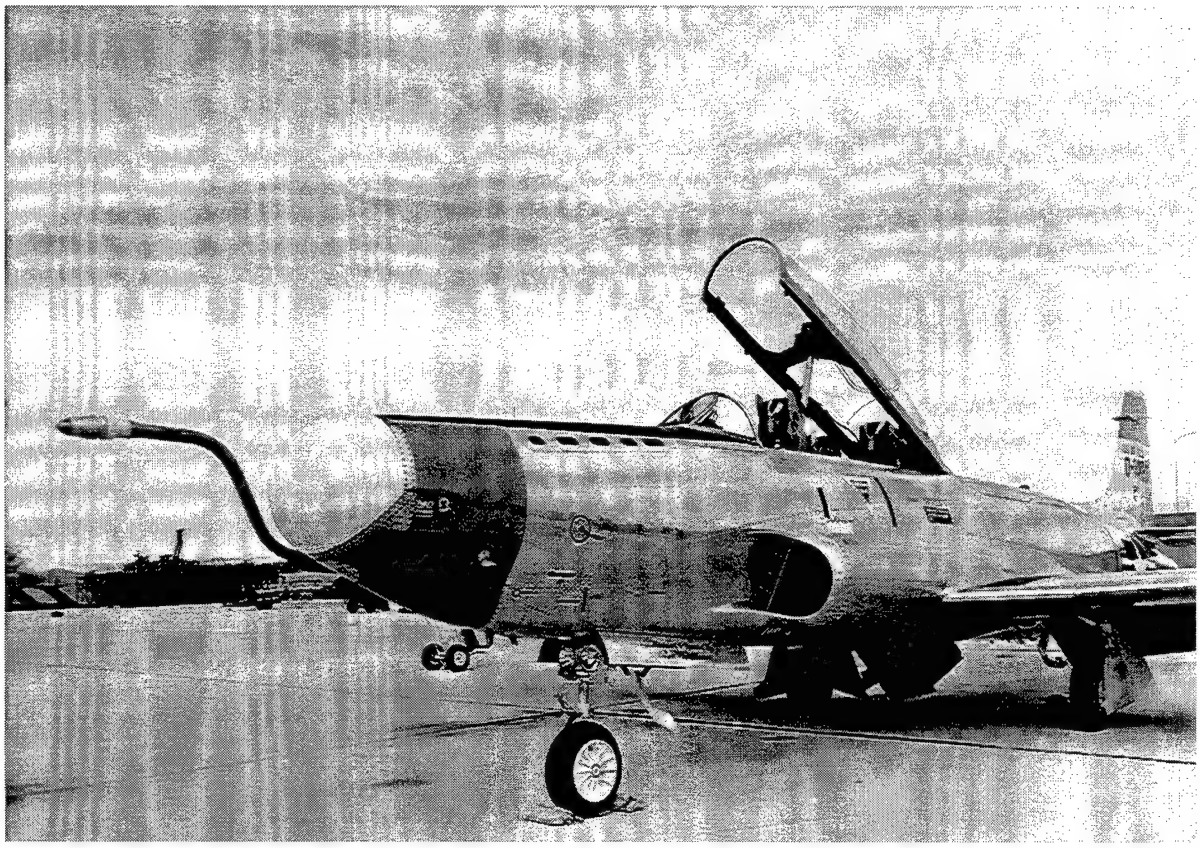

Figure F1 NT-33A Aircraft With MD-1 Type Probe Attached

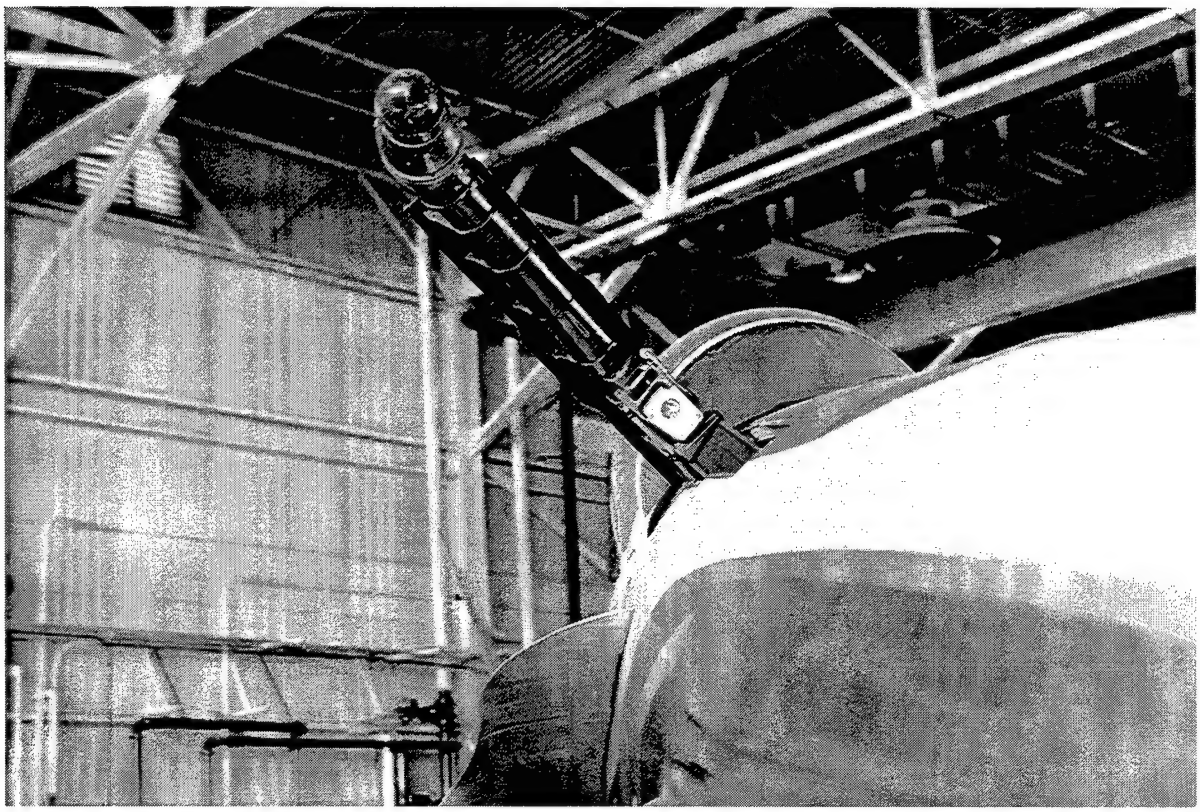

Figure F2 F/A-18B Aircraft With Aerial Refueling Probe Extended

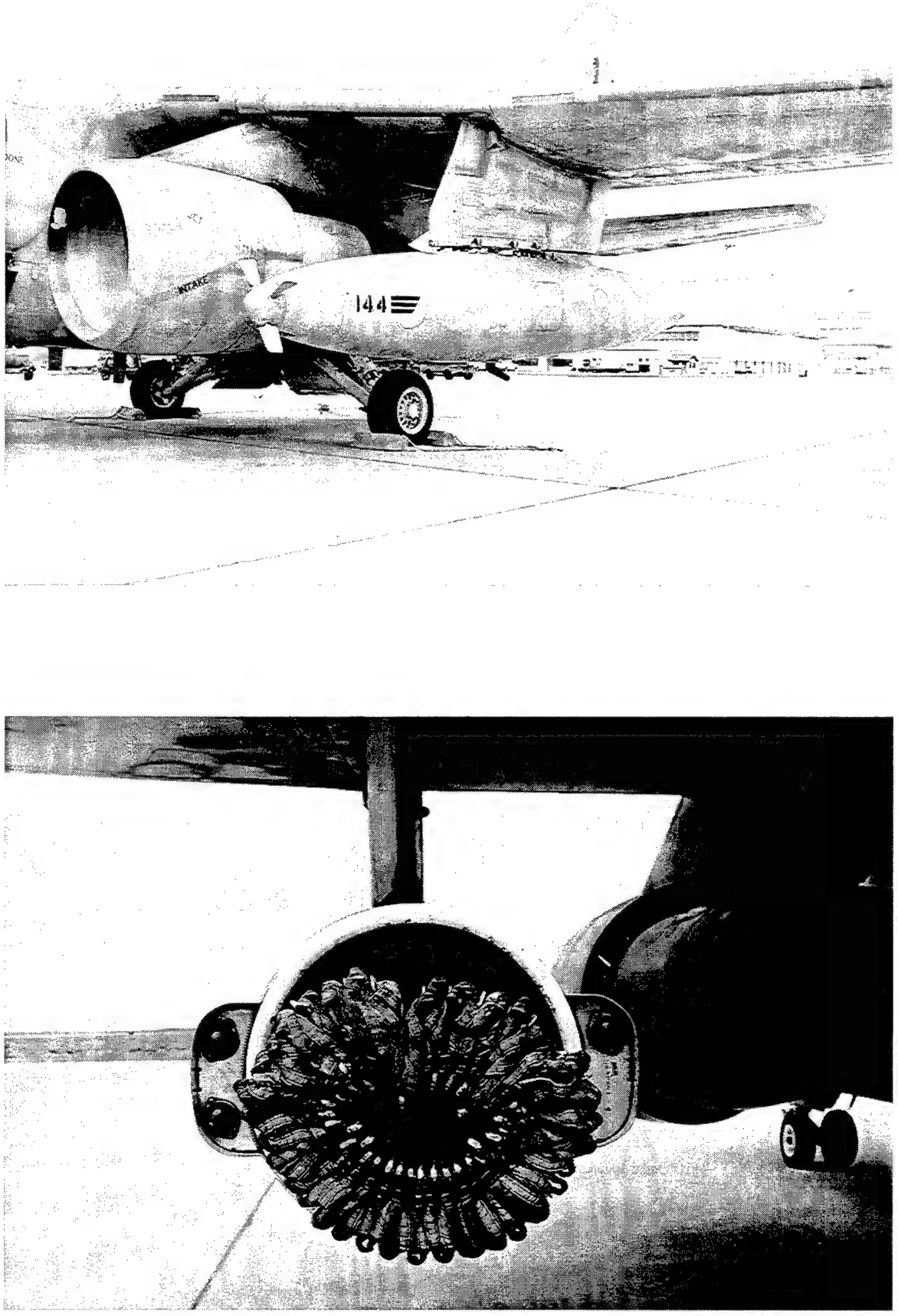

Figure F3 S-3B Tanker With SF-31-301 Aerial Refueling Store

APPENDIX G

NT-33A VARIABLE STABILITY FLIGHT CONTROL SYSTEM DESCRIPTION

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NT-33A VARIABLE STABILITY FLIGHT CONTROL SYSTEM DESCRIPTION

VARIABLE STABILITY FLIGHT CONTROL SYSTEM DESCRIPTION

The original T-33 nose section has been replaced with the larger F-94 nose to provide the volume required for the electronic components of the variable stability flight control system and recording equipment. The physical layout of the variable stability system (VSS) flight controls is shown in Figure G1. The elevator, rudder, and ailerons are connected to individual hydraulic servos controlled by the VSS. Electrical inputs from the pilot controls, alpha vane, beta probe, rate gyros, and accelerometers provide feedback to the VSS and can be adjusted inside the aircraft. This arrangement allows the normal T-33 aircraft stability parameters to be augmented to the extent that it can simulate many current, future, and hypothetical research aircraft flight control configurations. A more detailed description on the flight control system can be found in Reference 4.

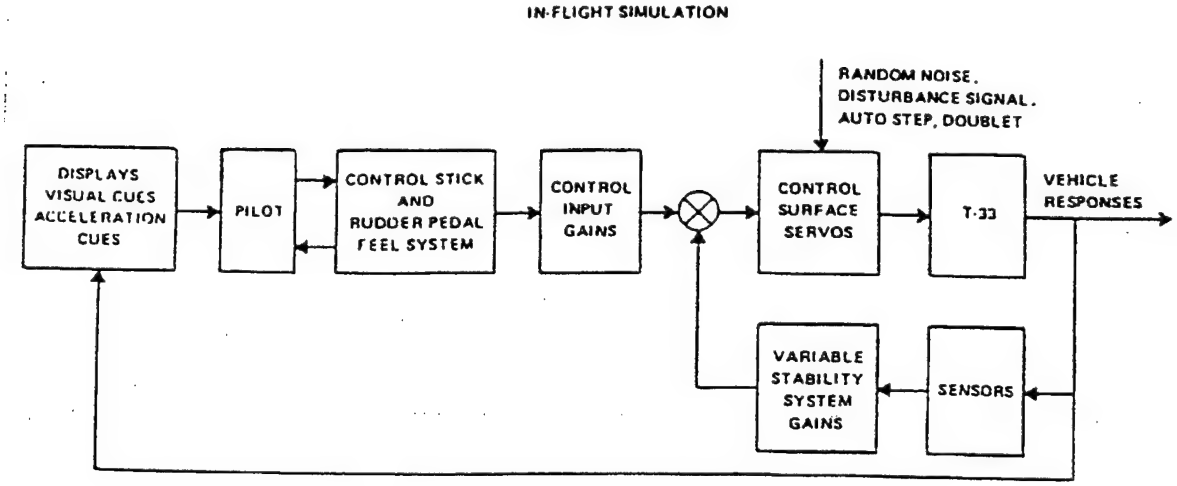

Figure G1 Variable Stability Flight Control System

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APPENDIX H

SF-31-301 REFUELING STORE

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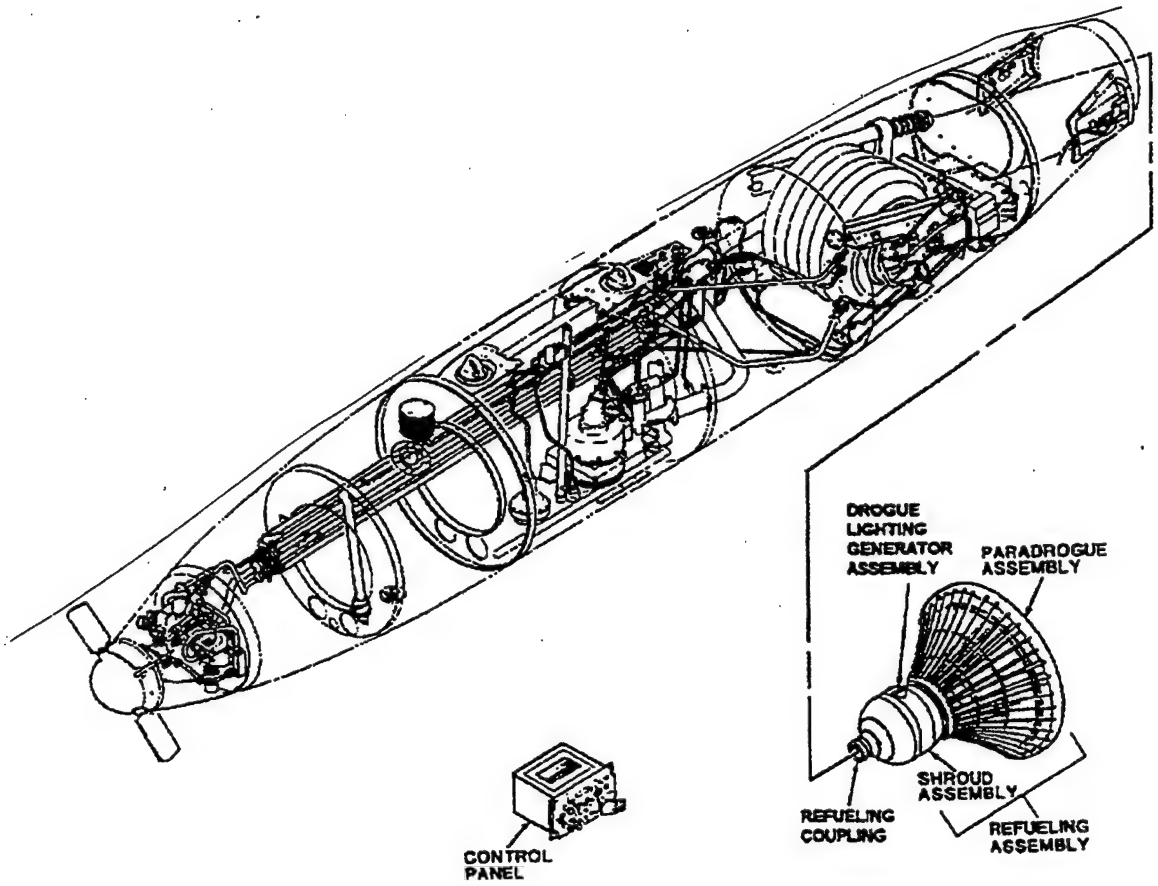

Figure H1 SF-31-301 Aerial Refueling Store

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APPENDIX I

DATA SORTIE NO. 1 RESULTS

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DATA SORTIE NO. 1 RESULTS

RESULTS FROM SORTIE NO. 1

There was no opportunity to optimize the NT-33A stick gain for probe-and-drogue refueling before the test project, due to lack of probe-and-drogue tanker assets prior to the first flight. On the first NT-33A flight (data sortie No. 1), the stick gain corresponding to 25 pounds/g was too high which led all flight control system (FCS) configurations to be prone to pilot-induced oscillations (PIO). Since two training sorties were flown prior to the next data sortie, these sorties were used to optimize the stick gain. This gain, 37 pounds/g, was used on the remaining two NT-33A data flights. The impact on the test project was that Cooper-Harper (CH) and PIO ratings from the first data flight could not be used to compare with the results from the other data flights. Therefore, only pilot comments on the aerial refueling (AR) tasks were used from the first NT-33A data flight. The CH and PIO ratings obtained on sortie No. 1 are summarized in Table I1. The pilot's comments were that all tasks had to be flown at very low gain in order to perform the tasks at all.

Table I1
CH AND PIO RATINGS FROM DATA SORTIE NO. 1

	AR Hookup Task		Drogue Tracking Task		Drogue Aiming Task	
NT-33A FCS Configuration	CH	PIO	CH	PIO	CH	PIO
2D	4	1	5	1	6	3
2P	10	5	10	6	7	4
2H	10	5	10	5	9	4

Notes:
1. AR - aerial refueling
2. FCS - flight control system
3. CH - Cooper-Harper
4. PIO - pilot-induced oscillation

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition	Unit
AFB	Air Force Base	---
AFFTC	Air Force Flight Test Center	---
AR	air refueling	---
CH	Cooper-Harper	---
FCS	flight control system	---
HUD	head-up display	---
LOES	Lower Order Equivalent System	---
MIL-STD	military standard	---
NAS	naval air station	---
NASA	National Aeronautics and Space Administration	---
NATOPS	Naval Air Training and Operating Procedures Standardization	---
N/A	not applicable	---
PIO	pilot-induced oscillation	---
PROM	programmable read-only memory	---
TPS	Test Pilot School	---
VHS	very high speed	---
VSS	variable stability system	---
ζ_{sp}	short-period damping	dimensionless
ω_{sp}	short-period frequency	rad/sec
$\omega_{n\,sp}$	short-period natural frequency	rad/sec
USAF	United States Air Force	---
θ/δ_e	pitch per elevator	dimensionless

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